Chapter 4

Skull: Cranium and Mandible

The bones of the human skull can be divided into three basic types, with the bones of each type being derivatives of specific structures in or around the head of our aquatic ancestors. Most bones of the skull base lie underneath the brain and are at least partly preformed in cartilage. These bones represent the primitive vertebrate braincase. The facial bones and bones of the roof and sides of the skull are dermal bones, formed in sheets of connective tissue under the skin. Dermal bone served as an armor plating for the primitive fishes, especially as a protective covering for the vital head parts. The rest of the bones of the skull are derived from the gill arches of primitive fish ancestors. Primitive vertebrates had no jaws. The earliest jaws were derived from the first, or mandibular, gill arch. Bones of this structure moved forward under the braincase to become the upper and lower jaws. These primitive jaws became sheathed in, and were eventually replaced by, dermal bones. Meanwhile, original gill arch bones migrated to the middle ear region, where they became two of the three tiny bones associated with hearing.

The skull is the most complex portion of the skeleton and is of major importance in human osteology. It is one of the keys to aging, sexing, and understanding the evolutionary history of hominids. The complexity of the human skull can best be understood by recognizing the widely differing functions it performs. It forms the bony foundation for the senses of sight, smell, taste, and hearing. It houses and protects the brain. In addition, the skull forms the framework of the chewing apparatus. Given these varied functions, it is no wonder that the skull is a complex structure.

Before moving to a detailed consideration of the individual bones of the skull, it is useful to consider this part of the anatomy as a unit (Figures 4.1–4.7). The following terms refer to some of the most convenient landmarks to use when considering the skull as a whole. The eye sockets are the **orbits**. The hole between and below the orbits, the nose hole, is the **anterior nasal aperture**, or **piriform aperture**. The ear holes are **external acoustic meati** (the singular is **meatus**), and the large oval hole in the base of the skull is the **foramen magnum**. The thin bony bridges at the sides of the skull are the **zygomatic arches**. The teeth are part of the skull, but because of their importance and peculiar anatomy an entire chapter is devoted to them (Chapter 5).

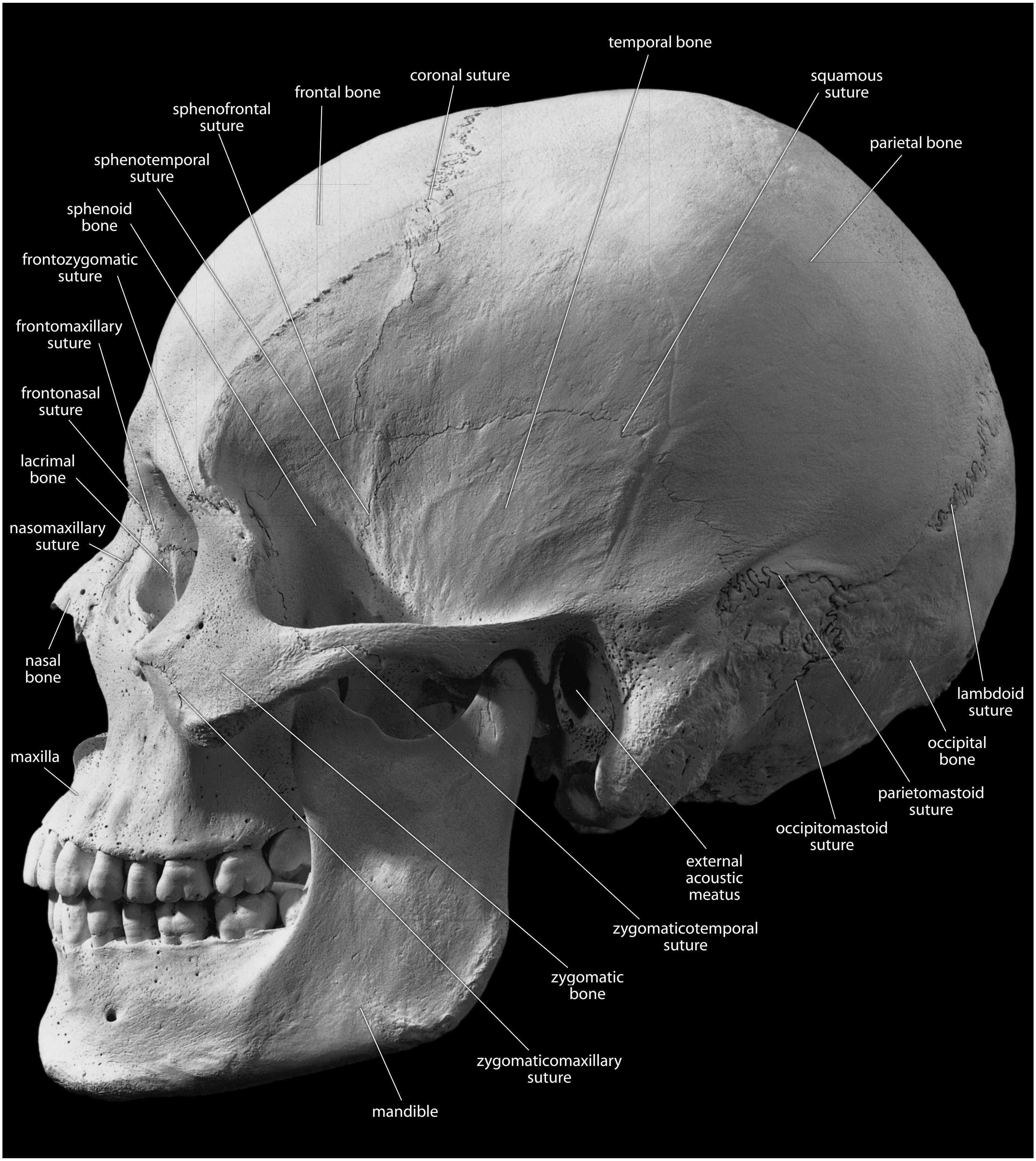


Figure 4.1 **Adult male skull, lateral.** Natural size.

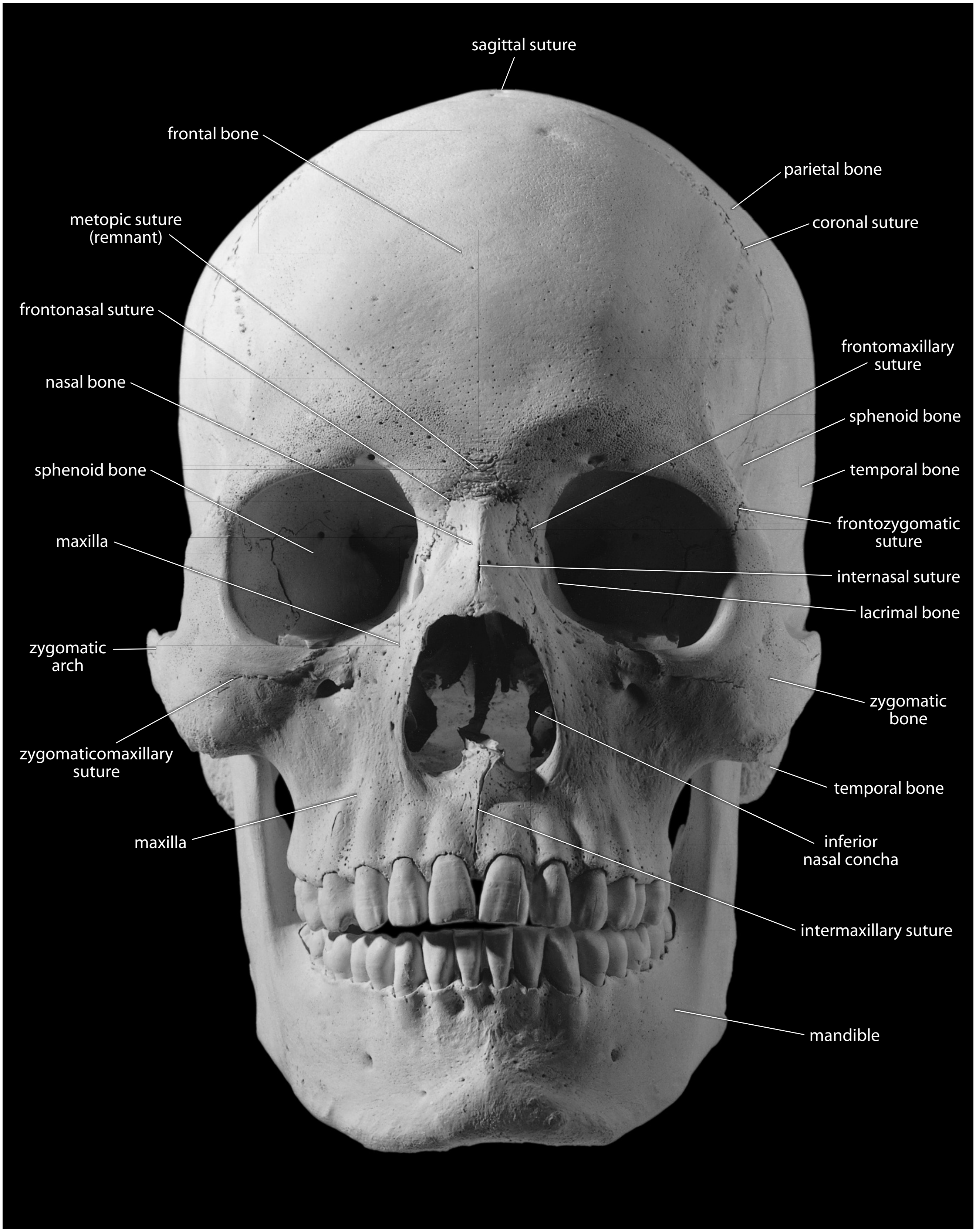


Figure 4.2 **Adult male skull, anterior.** Natural size.

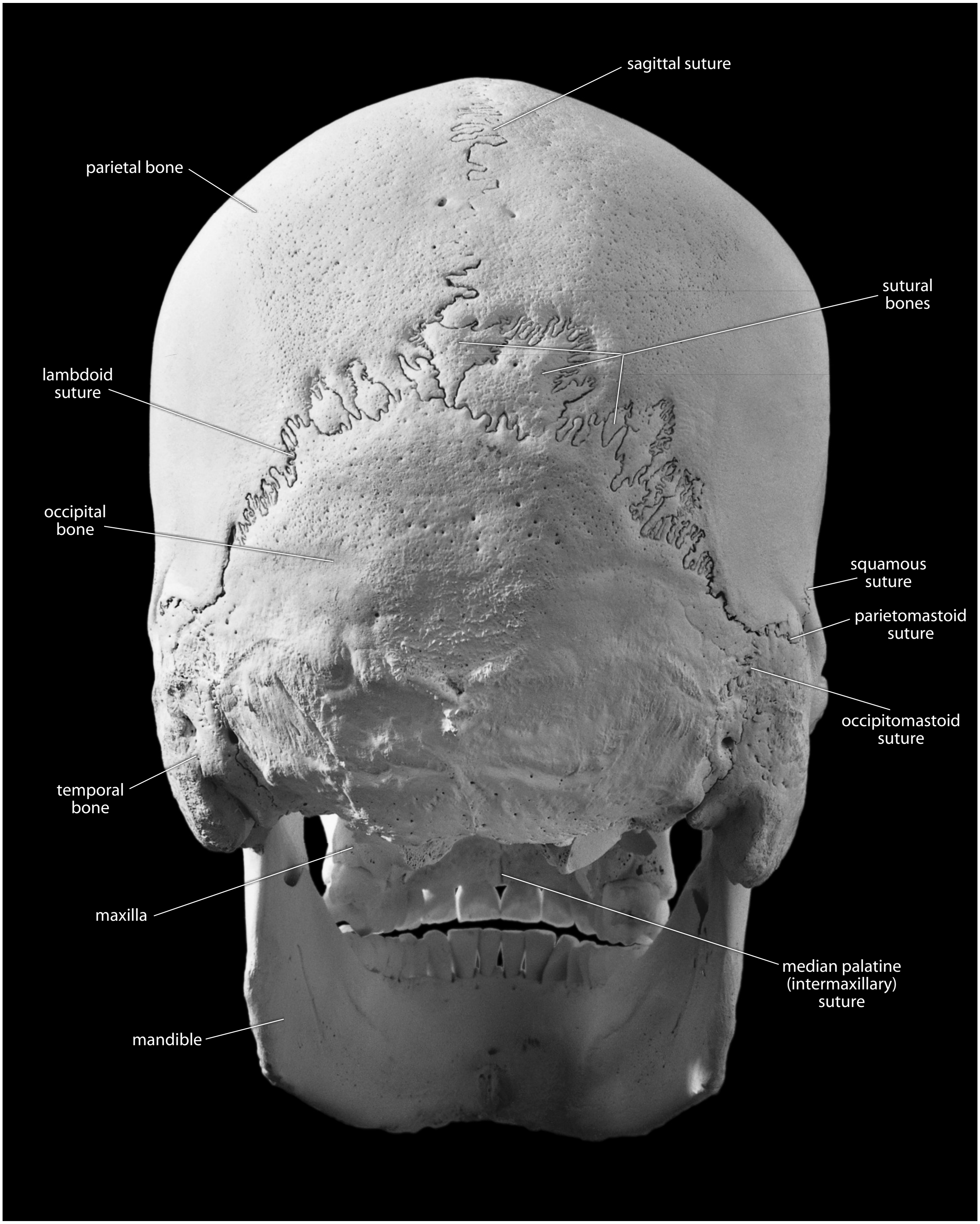


Figure 4.3 **Adult male skull, posterior.** Natural size.

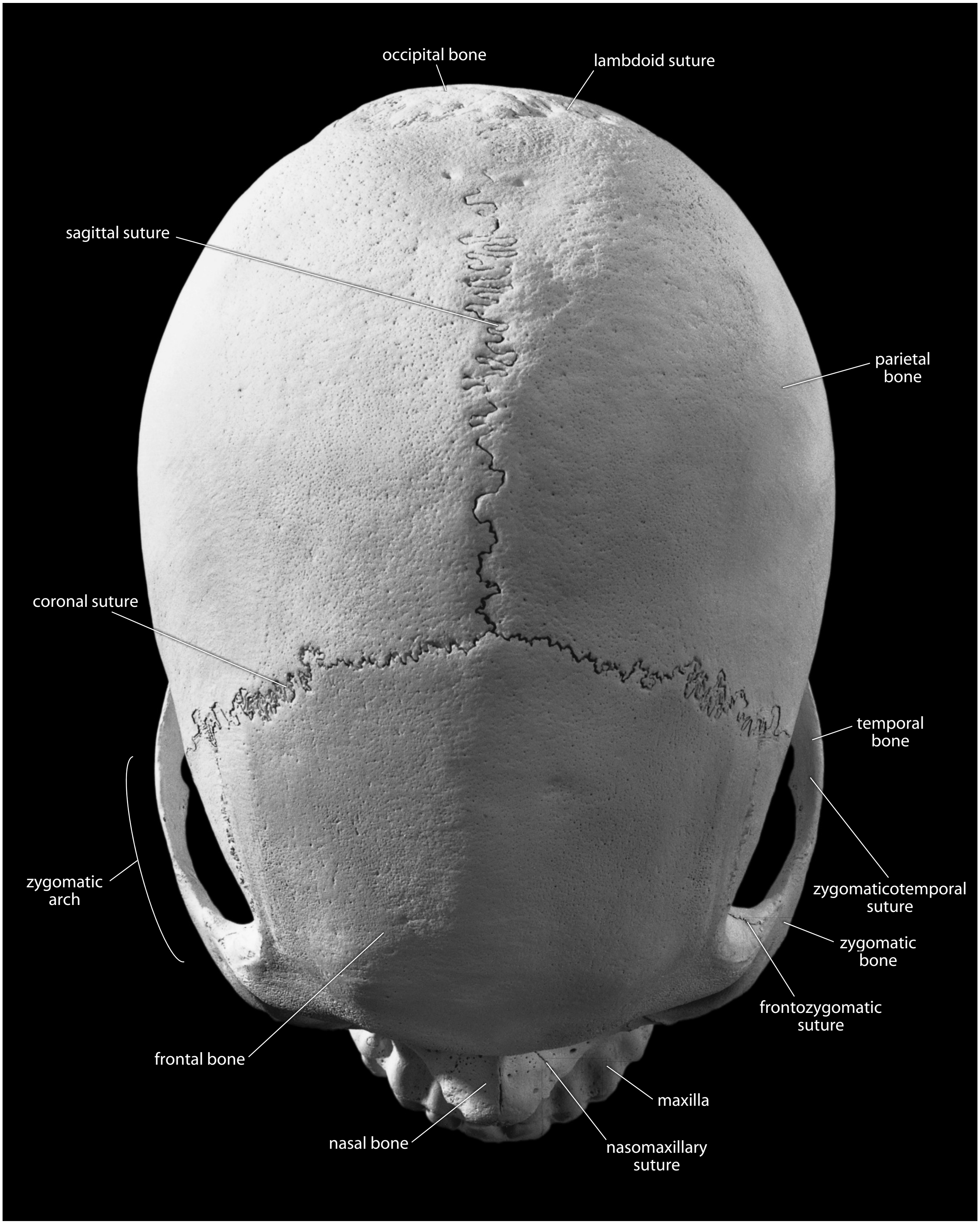


Figure 4.4 **Adult male cranium, superior.** Natural size.

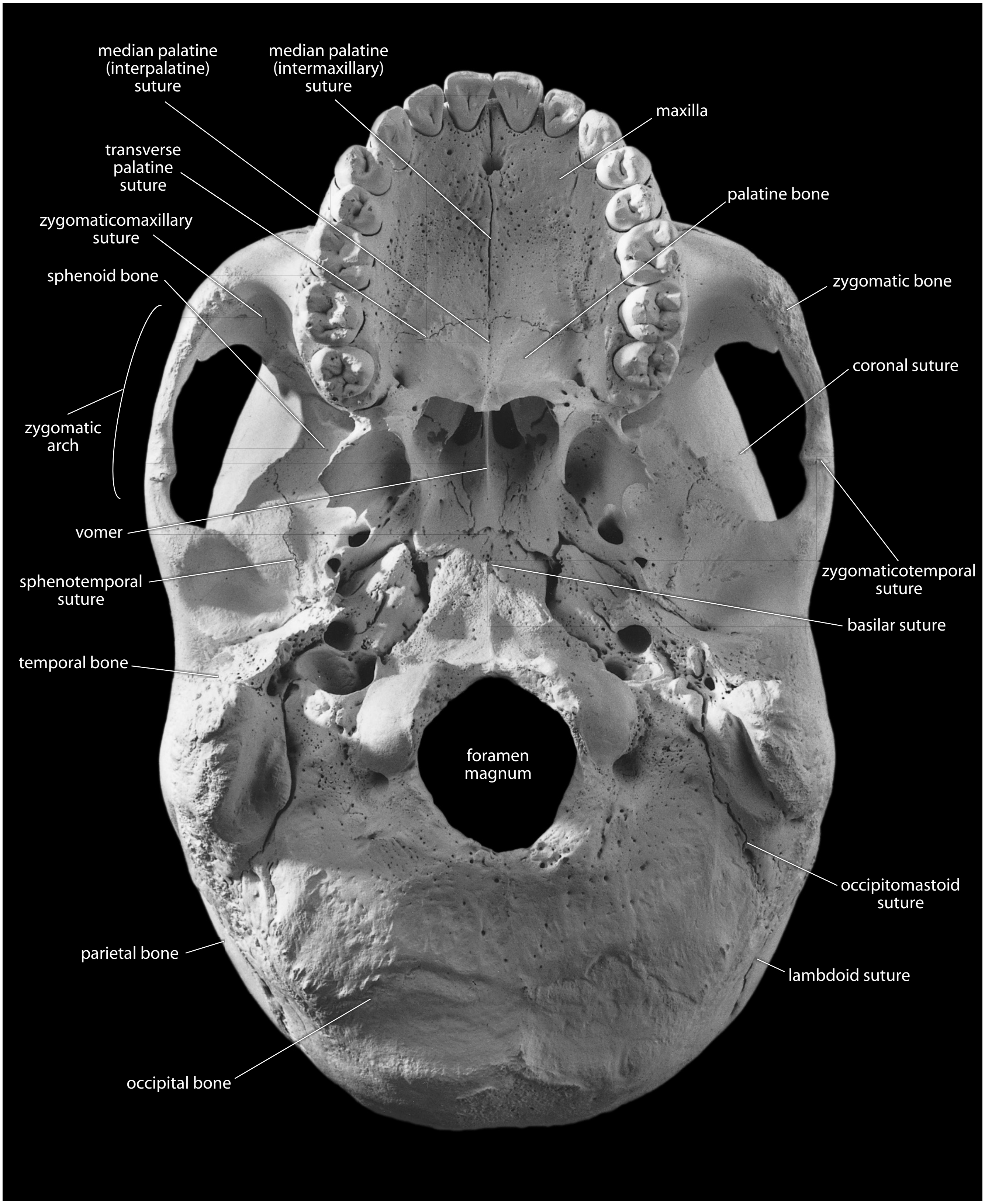


Figure 4.5 **Adult male cranium, inferior.** Natural size.

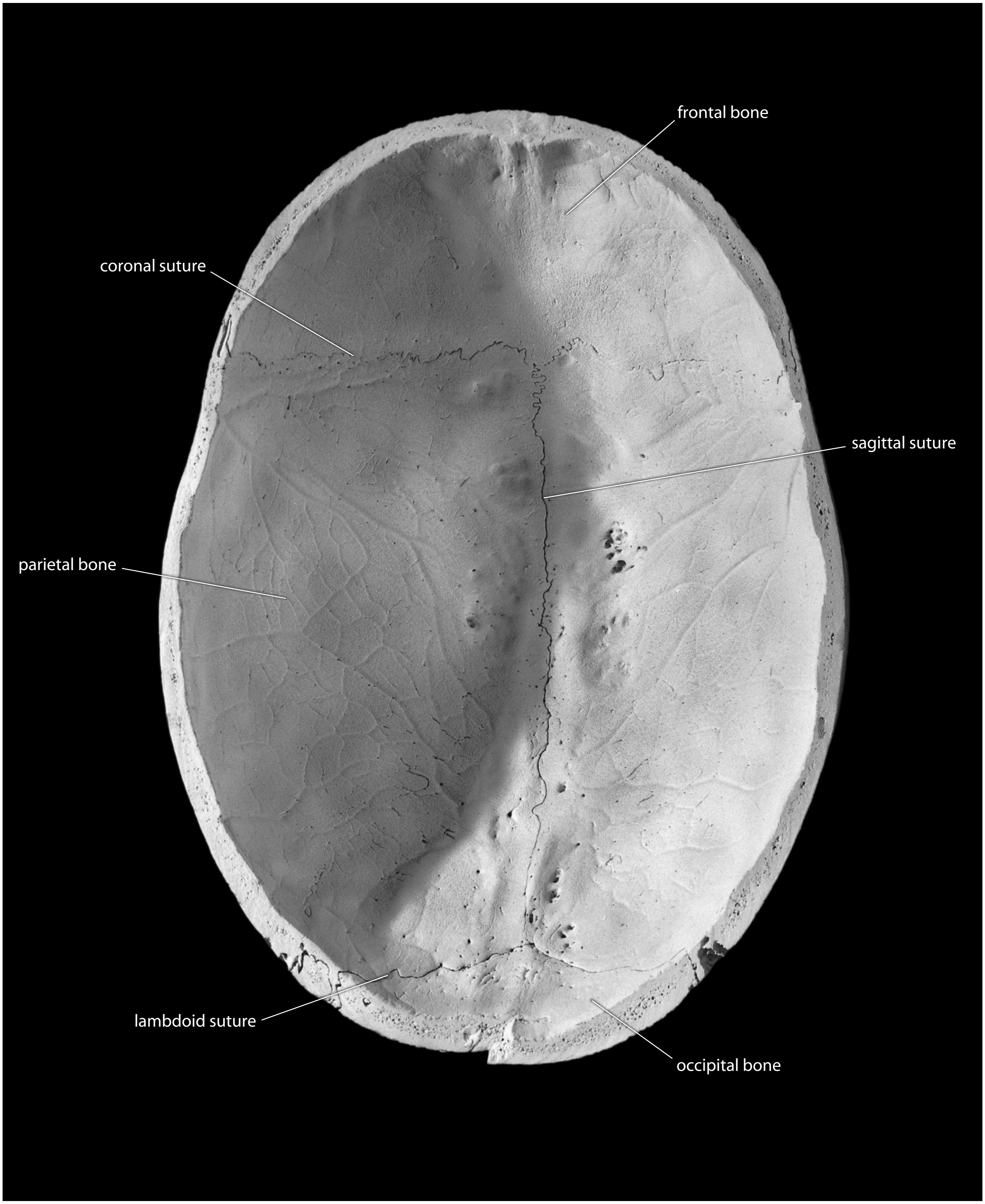


Figure 4.6 **Adult male cranium, endocranial, superior part.** Natural size.

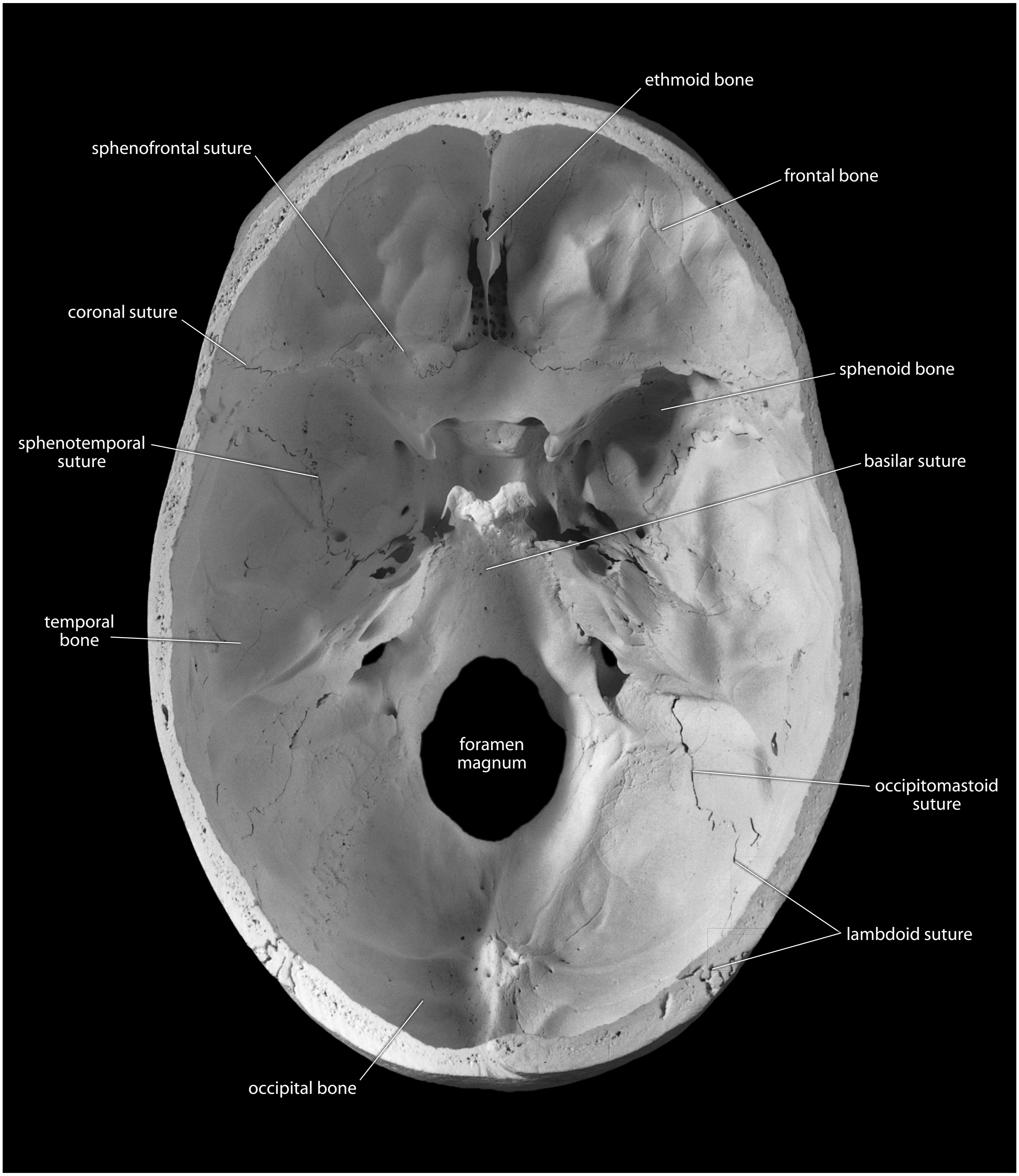


Figure 4.7 **Adult male cranium, endocranial, inferior part.** Natural size.

4.1 Handling the Skull

In addition to being one of the most complex parts of the skeleton, some of the elements of the skull are also the most delicate. During study, the skull should be handled above a padded surface and stabilized against rolling on the surface by means of sandbags or cloth rings designed for this purpose. It is rarely necessary to store or manipulate the lower jaw in its natural anatomical position relative to the upper jaw. When this position is called for, however, note that the colliding upper and lower teeth are fragile and susceptible to chipping. Care should be exercised when occluding the upper and lower jaws in this fashion, and padding should always be placed between the teeth if the skull is stored in this position.

In handling the skull, always use common sense and both hands. A finger or thumb placed in and behind the foramen magnum will not damage the bone, but other openings, such as the orbits or zygomatic arches, are more fragile and should never be used as gripping surfaces. In addition to the thin bones within the orbits, those delicate parts that are susceptible to damage during cranial manipulation include the edges and insides of the nasal aperture as well as the thin, projecting pterygoid plates and styloid processes at the base of the skull. If a tooth becomes dislodged during study, place it into a clear plastic bag and label the bag with the specimen number and the position of the tooth.

The temptation to test the mechanical properties of dry bone by probing, twisting, poking, stabbing, shaking, or scraping should always be resisted. However, in the course of handling osteological material, breakage does occur. Fortunately, it is normally a simple matter to glue the bone back together. This should be done promptly by the laboratory supervisor so that the broken pieces are not lost permanently (Chapter 16).

4.2 Elements of the Skull

The term "skull" is often misused in common speech. Terms such as this have very specific meanings to anatomists and osteologists. It is worthwhile to review the proper use of terminology.

- The **skull** is the entire bony framework of the head, including the lower jaw.
- The **mandible** is the lower jaw.
- The **cranium** is the skull without the mandible.
- The **calvaria** (or **calvarium**) is the cranium without the face.
- The **calotte** is the calvaria without the base.
- The **splanchnocranium** is the facial skeleton.
- The **neurocranium** is the braincase.

The three basic divisions of the endocranial surface at the base of the neurocranium correspond to the topography of the base of the brain. These anterior, middle, and posterior cranial fossae are respectively occupied by the frontal lobes, temporal lobes, and cerebellum of the brain.

When the ear ossicles (three pairs of tiny bones associated with hearing) are included and the hyoid excluded, there are usually 28 bones in the adult human skull. Distinguishing these bones is occasionally made difficult because some of them fuse together during adult life. For this reason, it is advisable to begin study with young adult specimens, in which the bones are most readily recognizable. In addition to the 28 normal skull bones, there are often **sutural bones** (also called **Wormian bones**, or **extrasutural bones**), which are irregular ossicles that occur along some sutures. A large, triangular **inca bone** is occasionally found at the rear of human crania.

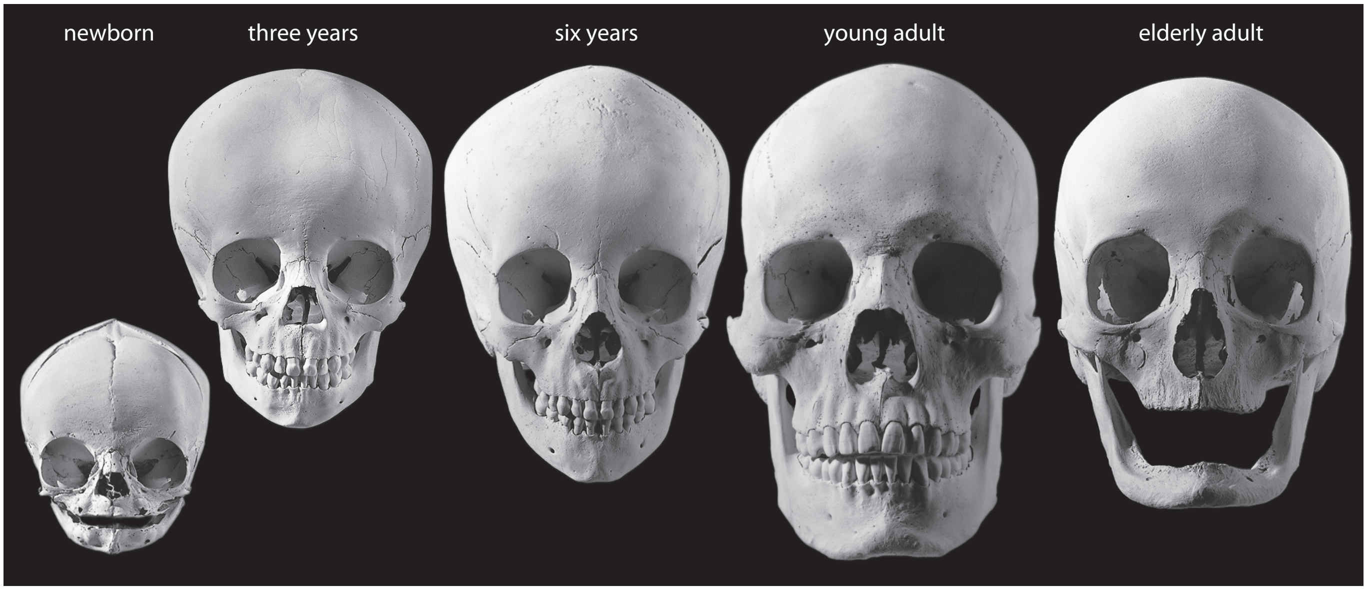


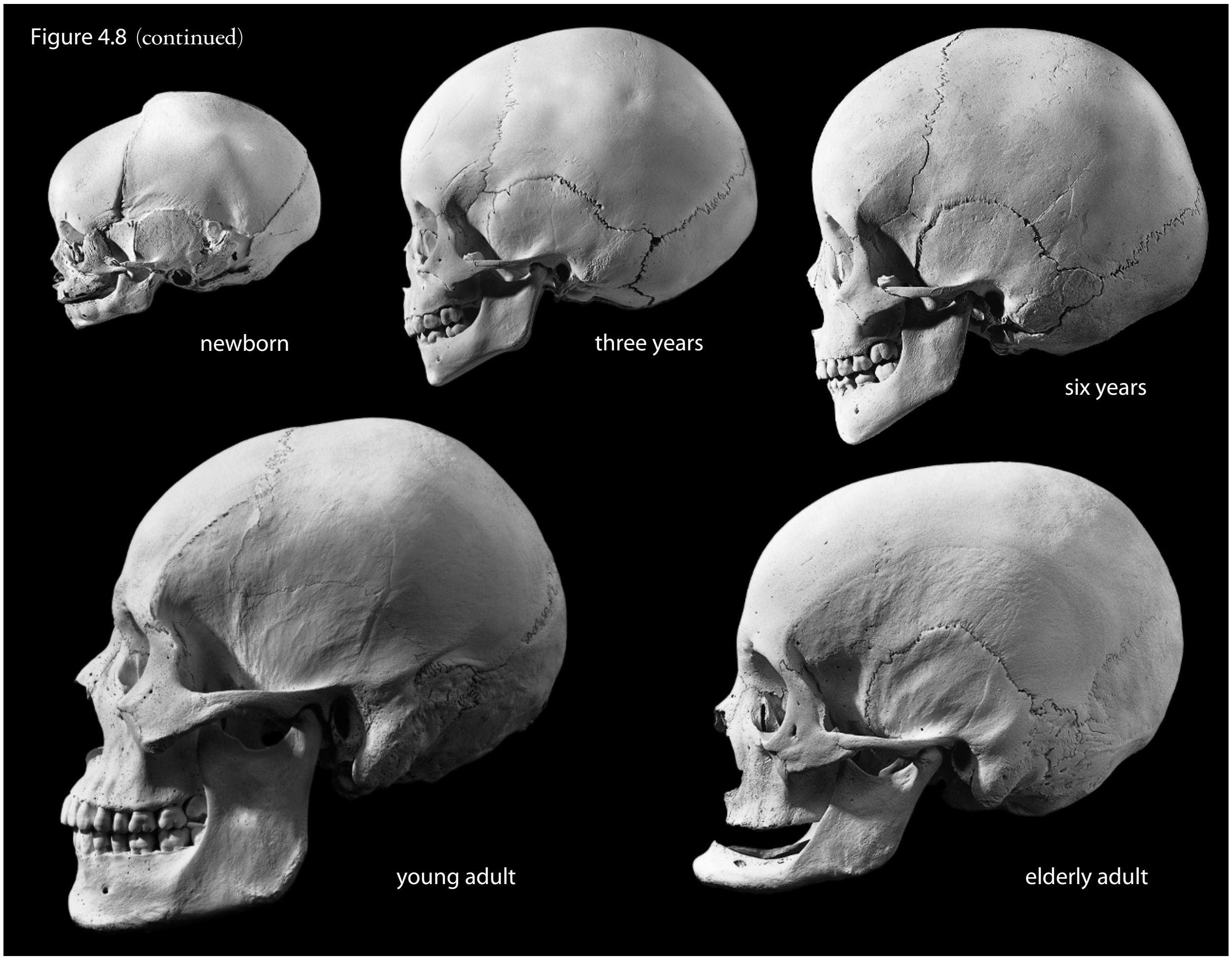
Figure 4.8 **Growth in the human skull**. (*Above* and *opposite*) Note the change in proportions of face and vault through the series. All specimens are shown in facial and lateral views. Approximately one-third natural size.

4.3 Growth and Architecture, Sutures and Sinuses

The human skull is a fascinating structure when viewed from a phylogenetic perspective. In early vertebrates, two kinds of bone evolved, **dermal bone** and **cartilage-replacement bone**. The modern human skull is derived from both kinds of bone. Dermal bones form the sides and roof of the skull and make up the facial skeleton. The bones of the cranial base, known collectively as the **basicranium**, are mostly preformed in cartilage: the **ethmoid bone** surrounds the olfactory apparatus and nerves, the **sphenoid bone** surrounds the optic nerves, the two **temporal bones** surround the auditory system, and the **occipital bone** surrounds the spinal cord. Some bones, like the occipital, sphenoid, and temporal, combine dermal and cartilage-replacement portions. The remaining bones in the skull (mandible, greater wings of the sphenoid, ear ossicles, hyoid) are derived from the gill arches of primitive vertebrates.

At birth the skull is made up of 39 separate elements and is large relative to other parts of the body. The facial part of the newborn skull, however, is relatively small, reflecting the dominance of brain development at this stage of maturation. The face "catches up" to the neurocranium as development, particularly in the mandible and maxilla, proceeds. Important stages in the development of the skull include emergence of the first set of teeth (between the ages of 6 and 24 months), the emergence of the permanent teeth (beginning at about 6 years), and puberty. Figure 4.8 illustrates growth of the skull.

In the adult, the skull bones contact along joints with interlocking, sawtooth, or zipper-like articulations called **sutures**. Many of these sutures derive their name directly from the two bones that contact across them. For example, **zygomaticomaxillary sutures** are sutures between the zygomatics and maxillae, and **frontonasal sutures** are short sutures between the frontal and nasals. Some sutures have special names. The **sagittal suture** passes down the midline between the parietal bones. The **metopic** (or **frontal**) **suture** passes between unfused frontal halves and only rarely persists into adulthood. The **coronal suture** lies between the frontal and parietals. The **lambdoid** (or **lambdoidal**) **suture** passes between the two parietals and the occipital. **Squamous sutures** are unusual, scale-like, beveled sutures between temporal and parietal bones. The **basilar suture** (which, before fusion, is called the **sphenooccipital synchondrosis**) lies between the



sphenoid and the occipital. **Parietomastoid sutures** pass between the parietals and the temporals, constituting posterior extensions of the squamous suture. **Occipitomastoid sutures** pass between the occipital and temporals on either side of the vault.

Before adulthood, several of these sutures are preformed as **synchondroses** — semi-rigid joints made with hyaline cartilage. These synchondroses are temporary and will eventually be replaced either by **syndesmoses** — rigid ligamentous joints — or by bony fusion. These synchondroses are named differently than sutures: the **sphenooccipital synchondrosis** precedes the basilar suture, the **sphenopetrosal synchondrosis** precedes the sphenotemporal suture, the **petrooccipital synchondrosis** precedes the occipitomastoid suture, the **posterior intraoccipital synchondrosis** marks the site of future fusion of the squamous and lateral portions of the occipital bone, the **anterior intraoccipital synchondrosis** marks the site of future fusion of the basilar and lateral portions of the occipital bone, and the **sphenoethmoidal synchondrosis** precedes the sphenoethmoidal suture.

At birth the cranial vault has six areas which, instead of being covered by bone, are covered by dense connective tissue between plates of bone. These "soft spots," or **fontanelles**, are cartilaginous membranes that eventually harden and turn to bone. There are six fontanelles: two paired and two single. The **anterior** and **posterior fontanelles** are single, along the midline at either end of the sagittal suture. The **mastoid** and **sphenoidal fontanelles** are paired, with one of each on the right and left sides of the cranium.

Sinuses are void chambers in the cranial bones that enlarge with the growth of the face. There are four basic sets of sinuses, one each in the maxillae, frontal, ethmoid, and sphenoid. These sinuses are linked to the nasal cavity and, in life, irritation of their mucous membranes may cause swelling, draining, and headache-related discomfort.

4.4 Skull Orientation

The most useful and informative comparisons between skulls of different individuals are usually comparisons made with both skulls in the same orientation. The convention used in orienting the skull is the **Frankfurt Horizontal (FH)**, named for the city in which the convention was established in 1884. The Frankfurt Horizontal is a plane defined by three points: the right and left **porion** points (located at the top of each external acoustic meatus) and the left **orbitale** (located at the bottom of the left orbit). These and other craniometric landmarks are presented in Section 4.5.

Skulls are normally viewed from five standard perspectives, all in Frankfurt Horizontal (as illustrated in Figures 4.1–4.5). Viewed from above, the skull is seen in **norma verticalis**. When viewed from either side, the skull is seen in **norma lateralis**. **Norma occipitalis** is the posterior view of the skull. Viewed from the front the skull is seen in **norma frontalis**; viewed from the base it is seen in **norma basilaris**. All of these views are perpendicular or parallel to the Frankfurt Horizontal.

4.5 Craniometric Landmarks

Because the skull has been the focus of much physical anthropological investigation, an extensive network of craniometric landmarks has been developed to allow researchers to take comparable measurements on skulls. Early in the 20th century the main focus in physical anthropology was on measuring skulls and comparing these measurements. Today there is a return to an appreciation of the anatomy between the measuring points. Still, it is necessary to have a set of conventions to ensure unambiguous reporting and comparison of osteological material. In addition, even nonmetric descriptions often use a terminology of the skull which makes reference to these landmarks. Indeed, the vocabulary of the skull's measuring points is vital for researchers in osteology and paleontology. In Chapter 16 we provide information on how to measure osteological materials.

Before going into a more detailed discussion of cranial anatomy, we introduce the landmarks most frequently used in measurement and description of the human skull. These landmarks are defined for anatomically modern humans. Because of this, it may not be possible or useful to use them when measuring other extant or extinct primate species.

The craniometric landmarks are best considered in two basic sets: unpaired craniometric landmarks are located in the midsagittal plane, and paired landmarks lie on either side of this plane. Figures 4.9–4.11 indicate the major craniometric landmarks defined here.

Three basic kinds of cranial measurements are most often used. The first is the familiar **cranial capacity**, which describes the volume within the neurocranium. Most measurements taken on the skull are **linear** measurements between two points, the line between the two points sometimes being referred to as a **chord**. The third kind of measurement is a curvilinear measurement called an **arc**. The observer should always take care to see that the landmarks being used for measuring points are unbroken and clearly visible. Comparisons should always be made between individuals of similar age. Exceptions to these cautions should always be noted in any osteology report. The list of landmarks given here includes most points in use today. For a slightly extended list, see Martin and Saller (1957), the source of all abbreviations used here.

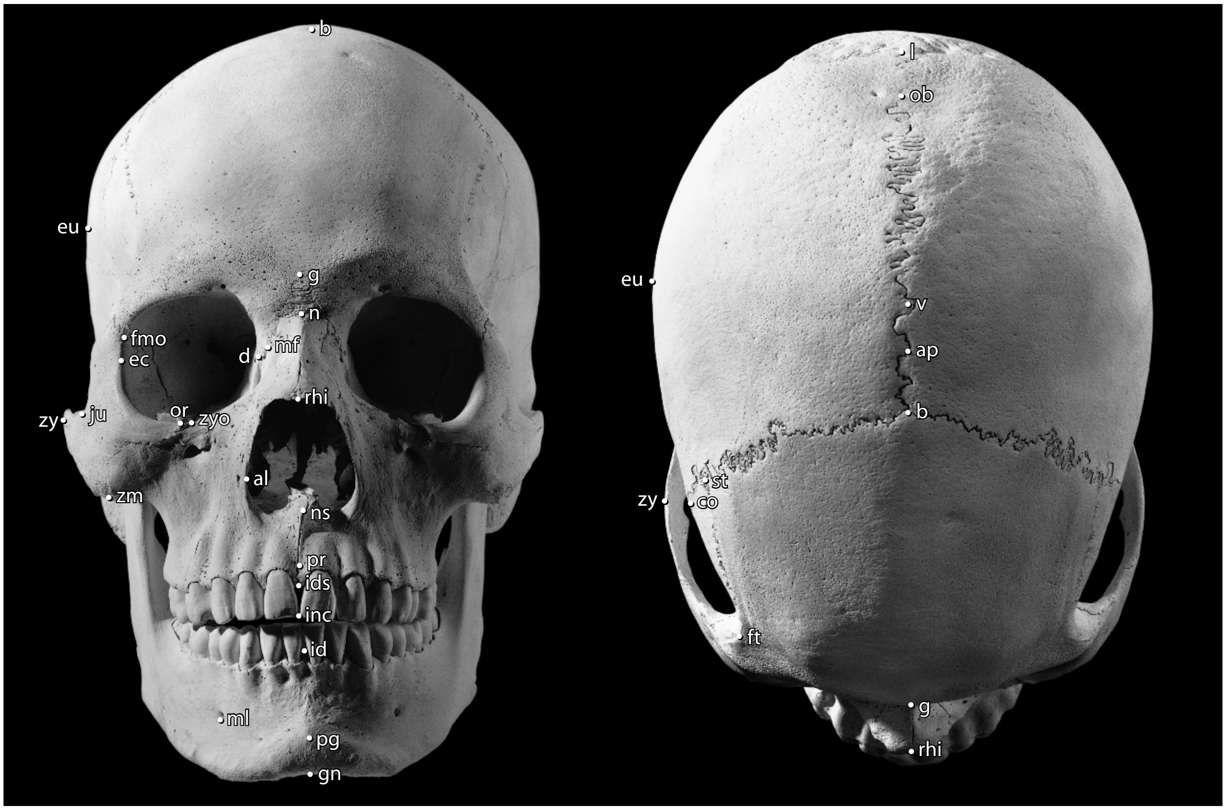


Figure 4.9 **Bones and osteometric points of the human skull.** *Left:* anterior; *right:* superior. One-half natural size.

4.5.1 Unpaired (Midline) Craniometric Landmarks

Note that the landmarks defined here are arranged in order from the upper incisors around the vault's midline to the lower incisors.

inc. **Incision** is the point at the occlusal surface where the upper central incisors meet.

ids. **Alveolare** (or **infradentale superius**) is the midline point at the inferior tip of the bony septum between the upper central incisors.

pr. **Prosthion** is the midline point at the most anterior point on the alveolar process of the maxillae.

ns. **Nasospinale** is the point where a line tangent to the inferiormost points of the two inferior curves of the anterior nasal aperture margin crosses the midline.

rhi. **Rhinion** is the midline point at the inferior free end of the internasal suture.

n. **Nasion** is the midline point where the two nasal bones and the frontal intersect.

g. **Glabella** is the most anterior midline point on the frontal bone, usually above the frontonasal suture.

m. **Metopion** is an instrumentally determined, ectocranial midline point on the frontal where the elevation of the frontal above the chord from nasion to bregma is greatest.

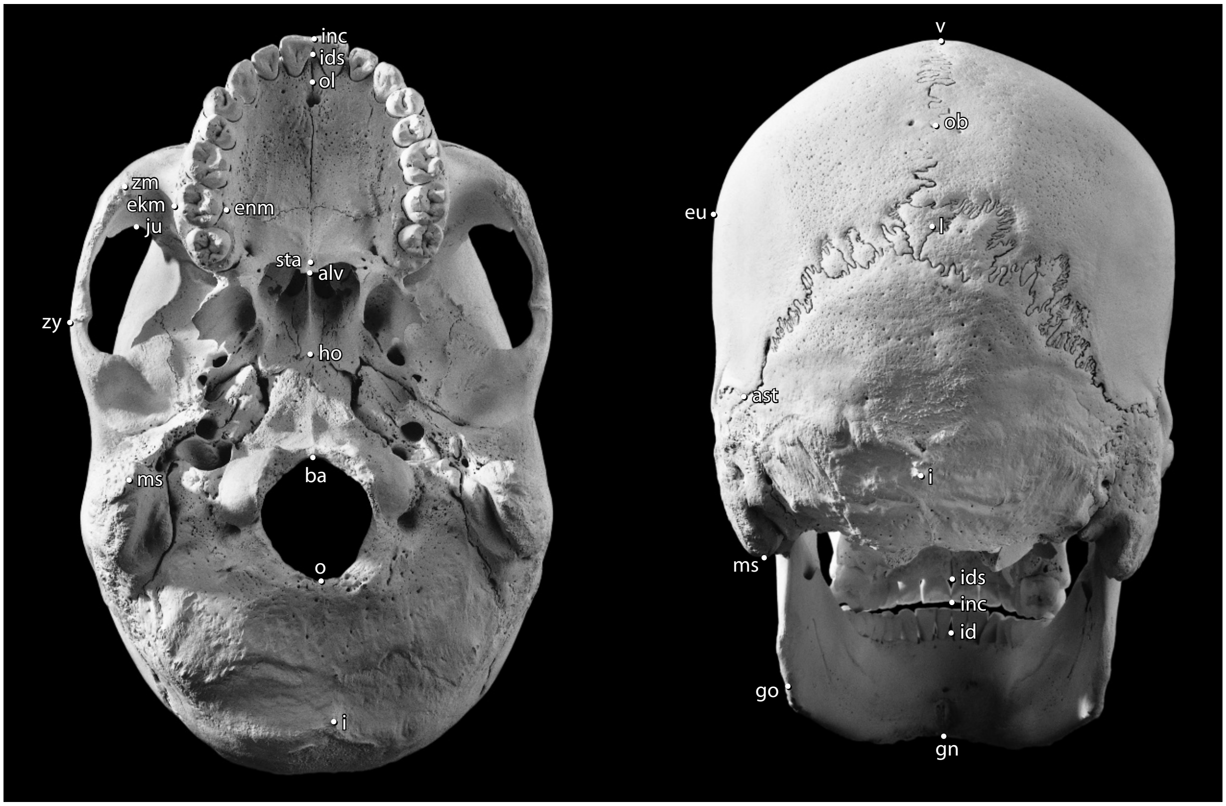


Figure 4.10 **Bones and osteometric points of the human skull.** *Left:* inferior; *right:* posterior. One-half natural size.

b. **Bregma** is the ectocranial point where the coronal and sagittal sutures intersect.

ap. **Apex** is an instrumentally determined, ectocranial midline point placed where a paracoronal plane through the right and left poria (Section 4.5.2) intersects the midsagittal skull outline.

v. **Vertex** is determined instrumentally when the skull is in Frankfurt Horizontal. It is the highest ectocranial point on the skull's midline.

ob. **Obelion** is an ectocranial midline point where a line connecting the parietal foramina (when present) intersects the midline.

l. **Lambda** is the ectocranial midline point where the sagittal and lambdoid sutures intersect. In cases such as the one illustrated in Figures 4.3 and 4.10, sutural bones make placement of this point difficult. When in doubt, choose the point where the lateral halves of the lambdoid suture and the lower end of the sagittal suture would be projected to meet.

op. **Opisthocranion** is an instrumentally determined point at the rear of the cranium. It is defined as the midline ectocranial point at the farthest chord length from glabella.

i. **Inion** is an ectocranial midline point at the base of the external occipital protuberance. The bony anatomy in this region is highly variable, with crests, lumps, or odd projections of bone possible. Normally, inion is defined as the point at which the superior nuchal lines merge in the external occipital protuberance.

o. **Opisthion** is the midline point at the posterior margin of the foramen magnum.

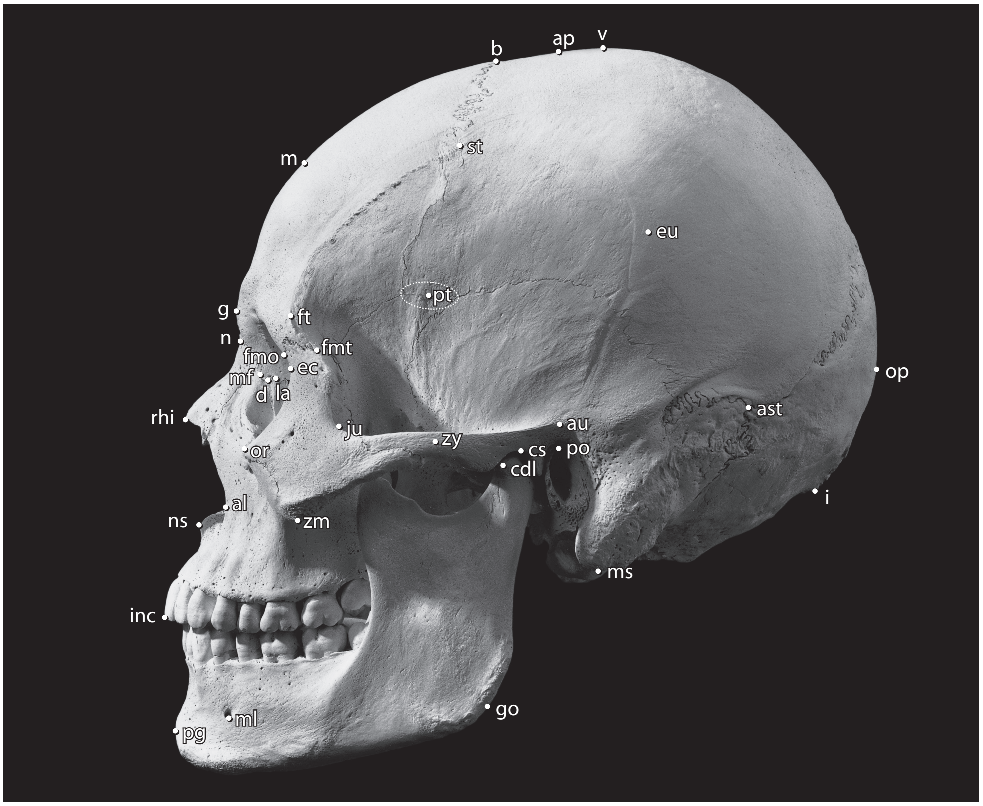


Figure 4.11 **Bones and osteometric points of the human skull, lateral.** One-half natural size.

ba. **Basion** is the midline point on the anterior margin of the foramen magnum. For cranial height measurements, the point is placed on the anteroinferior portion of the foramen's rim. For some measurements (*e.g.*, cranial base length and basion–prosthion length), the point is located on the most posterior point of the foramen's anterior rim and is sometimes distinguished as **endobasion**.

sphba. **Sphenobasion** is the point where the midsagittal plane intersects the basilar suture. This point has been obliterated by synchondrosis on the specimen illustrated in Figures 4.5 and 4.10.

ho. **Hormion** is the most posterior midline point on the vomer.

alv. **Alveolon** is the point on the median palatine (intermaxillary) suture where a line drawn between the posterior ends of the alveolar ridges crosses the midline.

sta. **Staphylion** is the point on the median palatine (intermaxillary) suture where a line drawn between the deepest parts of the notches (free edges) at the rear of the palate crosses the midline.

ol. **Orale** is the midline point on the hard palate where a line drawn tangent to the posterior margins of the central incisor alveoli crosses the midline.

gn. **Gnathion** is the most inferior midline point on the mandible.

pg. **Pogonion** is the most anterior midline point on the chin of the mandible.

id. **Infradentale** is the midline point at the superior tip of the septum between the mandibular central incisors.

4.5.2 Paired Craniometric Landmarks

zm. **Zygomaxillare** is the most inferior point on the zygomaticomaxillary suture.

al. **Alare** is instrumentally determined as the most lateral point on the margin of the anterior nasal aperture.

or. **Orbitale** is the lowest point on the orbital margin.

zy. **Zygion** is the instrumentally determined point of maximum lateral extent of the lateral surface of the zygomatic arch.

ju. **Jugale** is the point in the depth of the notch between the temporal and frontal processes of the zygomatic.

ec. **Ectoconchion** is instrumentally determined as the most lateral point on the orbital margin.

mf. **Maxillofrontale** is the point where the anterior lacrimal crest of the maxilla meets the frontomaxillary suture.

la. **Lacrimale** is the point where the posterior lacrimal crest meets the frontolacrimal suture.

d. **Dacryon** is the point where the maxillolacrimal suture meets the frontal bone.

zyo. **Zygoorbitale** is the point where the orbital rim intersects the zygomaticomaxillary suture.

fmo. **Frontomalare orbitale** is the point where the frontozygomatic suture crosses the inner orbital rim.

fmt. **Frontomalare temporale** is the point where the frontozygomatic suture crosses the temporal line (or outer orbital rim).

ft. **Frontotemporale** is the point where the temporal line reaches its most anteromedial position on the frontal.

st. **Stephanion** is the point where the coronal suture crosses the temporal line.

pt. **Pterion** is a region, rather than a point, where the frontal, temporal, parietal, and sphenoid meet on the side of the vault. The sutural contact pattern in this area is highly variable.

co. **Coronale** is the point on the coronal suture where the breadth of the frontal bone is greatest.

eu. **Euryon** is the instrumentally determined ectocranial point of greatest cranial breadth.

po. **Porion** is the uppermost point on the margin of the external acoustic meatus.

au. **Auriculare** is a point vertically above the center of the external acoustic meatus at the root of the zygomatic process, a few millimeters above porion.

ast. **Asterion** is the point where the lambdoid, parietomastoid, and occipitomastoid sutures meet.

ms. **Mastoidale** is the most inferior point on the mastoid process.

ekm. **Ectomolare** is the most lateral point on the outer surface of the alveolar margins of the maxilla, often at the second molar position.

enm. **Endomolare** is the most medial point on the inner surface of the alveolar margin opposite the center of the M^2 crown.

cdl. **Condylion laterale** is the most lateral point on the mandibular condyle.

cs. **Condylion superior** is the most superior point on the mandibular condyle.

cdm. **Condylion mediale** is the most medial point on the mandibular condyle.

cr. **Coronion** is the point at the tip of the coronoid process of the mandible (obscured in Figures 4.9–4.11).

go. **Gonion** is a point along the rounded posteroinferior corner of the mandible between the ramus and the body. To determine the point, imagine extending the posterior ramus border and the inferior corpus border to form an obtuse angle. The line bisecting this angle meets the curved gonial edge at gonion.

ml. **Mentale** is the most inferior point on the margin of the mandibular mental foramen.

4.6 Learning Cranial Skeletal Anatomy

To learn cranial skeletal anatomy, approach the skull systematically. First, study the skull of a young adult, observing all sutures between the bones. Then, study a growth series, noting how each bone and suture changes during ontogeny. Finally, use the descriptions in Sections 4.7–4.21 to learn the features of each bone of the skull. These features are the keys to identifying the various bones of the skull by element and side. Intact cranial bones have rather unique morphologies. You will rarely have difficulty differentiating them.

Because the various bones of the skull are often found in a disarticulated or fragmentary state, each bone or pair of bones must be given individual consideration. To identify and side fragments of the cranium, follow these steps: Determine whether the piece is cranial vault or face. Note any blood vessel impressions, sutures, foramina, surface textures, bone thickness changes, muscle attachments, sinus walls, or tooth roots or sockets. Note the thickness of the piece and its cross-sectional anatomy at the break, including sinus development. Carefully note the morphology of any visible sutures.

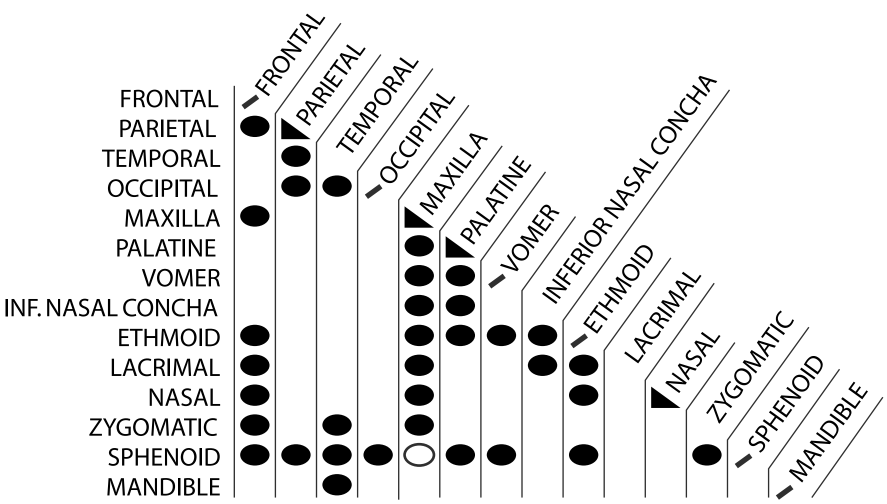


Figure 4.12 **Articulation of bones in the human skull.** Key: ⬬ : articulates; ◯ : sometimes articulates; ◣ : articulating pair; ⁄ : unpaired element.

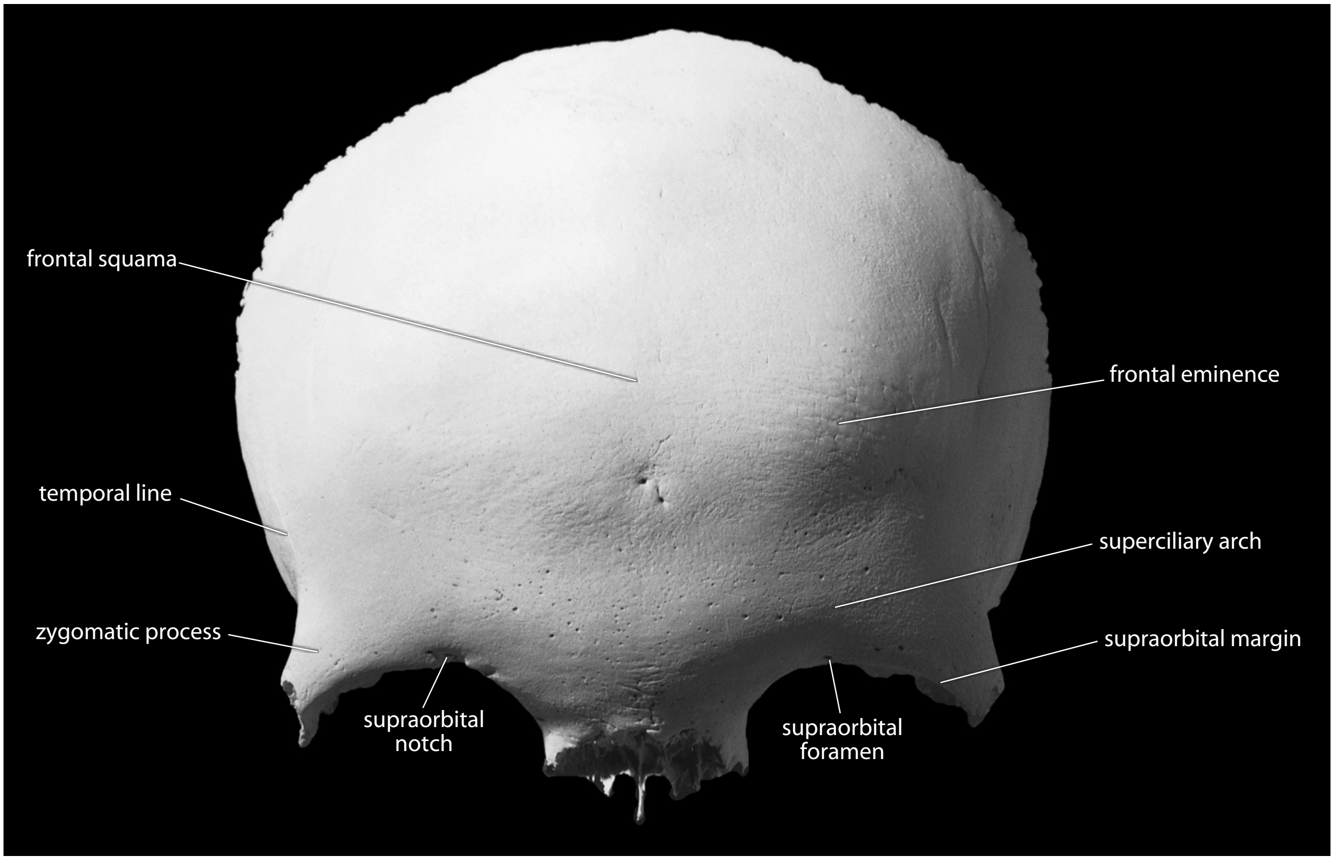
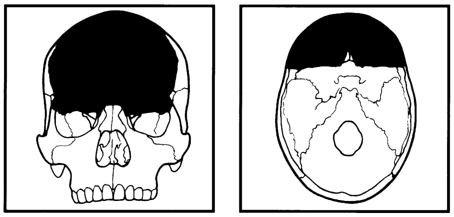


Figure 4.13 **Frontal, anterior (ectocranial)**. Natural size.



4.7 Frontal (Figures 4.13–4.16)

4.7.1 Anatomy

The frontal is located at the front of the neurocranium. It articulates with the parietals, nasals, maxillae, sphenoid, ethmoid, lacrimals, and zygomatics. The frontal is one of the largest and most robust cranial bones. It consists of two general parts: one vertical and one horizontal.

a. The vertical **frontal squama** forms the forehead.
b. The **horizontal portion** acts to roof the orbits and to floor the frontal lobes of the brain.
c. **Frontal eminences** (or **tubers** or **bosses**) dominate the ectocranial surface. These paired frontal bosses mark the location of the original centers of ossification of this bone.
d. **Temporal lines** on the lateral ectocranial surface mark the attachment of the *temporalis muscle*, a major elevator of the mandible, and its covering, the *temporal fascia*, a fascial sheet that covers the *temporalis*. The temporal line defines the superior edge of the temporal sur-

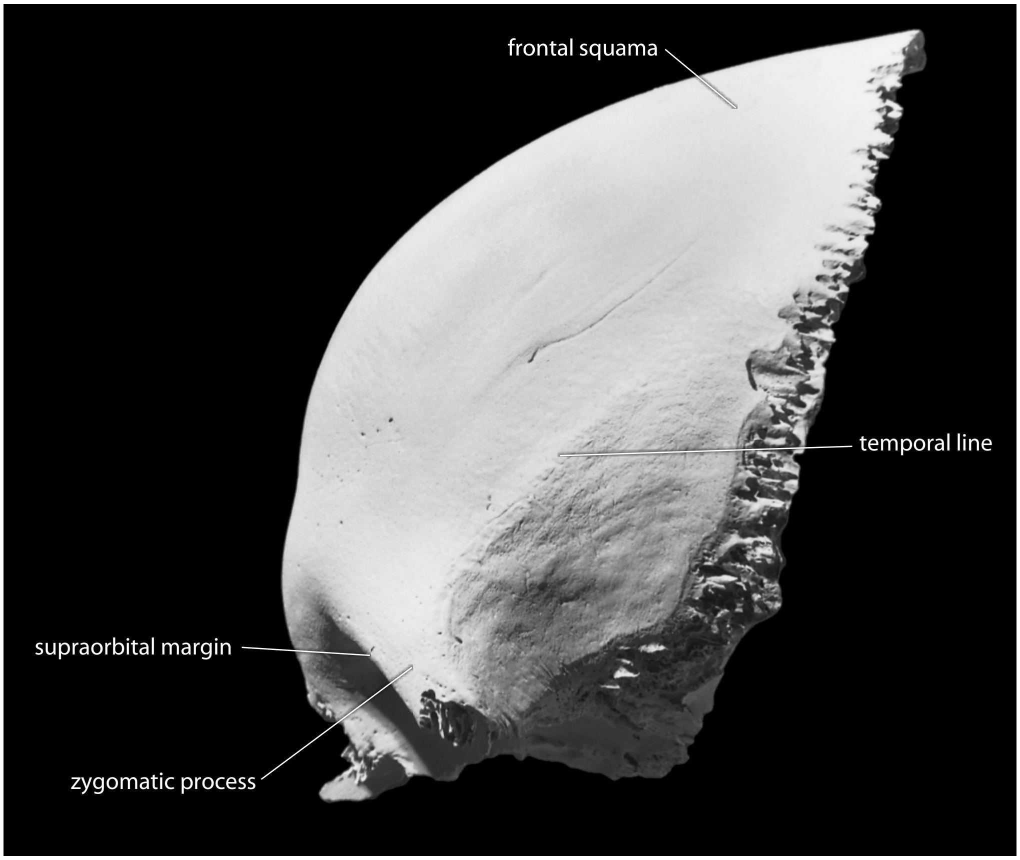


Figure 4.14 **Frontal, left lateral (ectocranial).** Natural size.

face (and fossa). This line becomes a crest in its anterior, lateral extent (on the zygomatic process of the frontal). It often divides into superior and inferior lines as it sweeps posteriorly.

e. **Zygomatic processes** form the most lateral and anterior corners of the frontal.

f. **Superciliary arches** (brow ridges) are the bony tori over the orbits. They are most prominent in males and are sometimes joined by a prominent glabellar region.

g. **Supraorbital margins** are the upper orbital edges. These are notched or pierced by the supraorbital notch or foramen.

h. **Supraorbital notches** (or **foramina**, if the notches are bridged) are set along the medial half of the superior orbital rim. They transmit the *supraorbital vessels* and *supraorbital nerve* as they pass superiorly to the forehead region.

i. The **metopic** (or **frontal**) **suture** is a vertical suture between right and left frontal halves. Its persistence is variable, but only occasionally does it last into adulthood. Traces of it are observed most often in the glabellar region in adults.

j. **Meningeal grooves** for the *middle meningeal arteries* are present on both sides of the concave endocranial surface of the frontal squama. The *brain* is covered with a tough outer protective membrane, the *dura mater*, whose blood supply comes from the *meningeal arteries*.

k. The **sagittal sulcus** is a vertical groove that runs down the midline of the endocranial surface. It lodges the *superior sagittal sinus*, a large vessel that drains blood from the brain.

l. The **frontal crest** is a midline crest confluent with the anterior end of the sagittal sulcus.

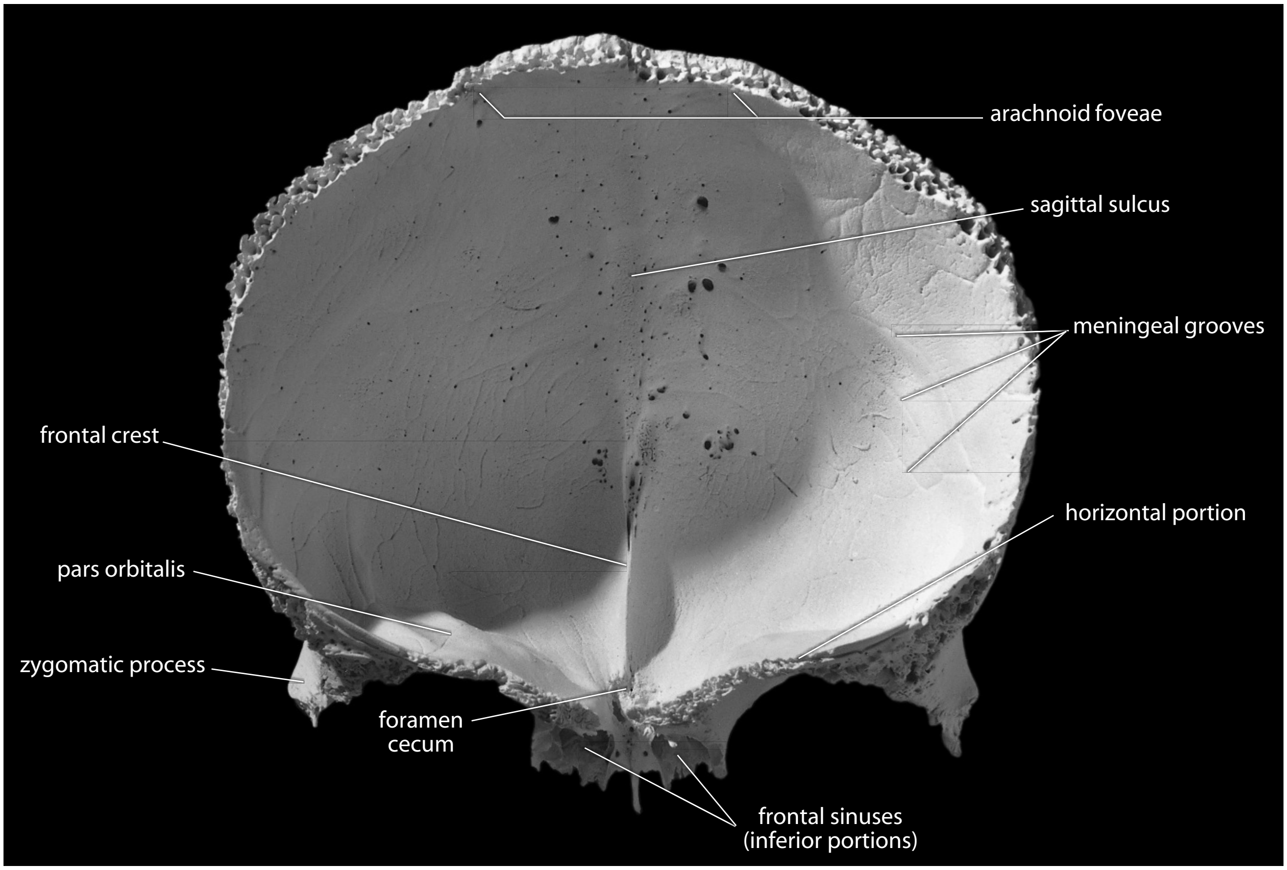


Figure 4.15 **Frontal, posterior (endocranial).** Natural size.

This crest gives attachment to the *falx cerebri*, a strong membrane between the two cerebral hemispheres of the brain.

m. The **foramen cecum**, a foramen of varying size, is found at the root, or base, of the frontal crest and transmits a small vein from the frontal sinus to the superior sagittal sinus.

n. **Arachnoid** (or **granular**) **foveae** are especially apparent near the coronal suture along the endocranial midline. They are features associated with another covering layer of the brain, the *arachnoid*, which is a delicate, avascular membrane lying beneath the *dura mater*. Tufts of *arachnoid*, the *arachnoid granulations*, push outward against the *dura*, causing resorption of the bone and the formation of foveae on the endocranial surface. On both sides of the midline the endocranial surface of the frontal bears depressions for convolutions of the frontal lobes of the brain.

o. The **pars orbitalis**, or **orbital plate**, is the horizontal portion of the frontal. Its endocranial surface is undulating (bumpy), conforming to the inferior surface of the frontal lobe. Its inferior surface (orbital surface) is smoother and concave.

p. **Lacrimal fossae**, for the *lacrimal glands*, are found at the lateral, inferior parts of the orbital (inferior) surfaces of the frontal.

q. The **ethmoidal notch** is the gap separating the two orbital plates of the frontal. The ethmoid bone fills this notch in the articulated cranium.

r. **Frontal sinuses**, generally anterior to the ethmoidal notch, extend for a variable distance between outer and inner bone tables of the frontal and sometimes penetrate the orbital

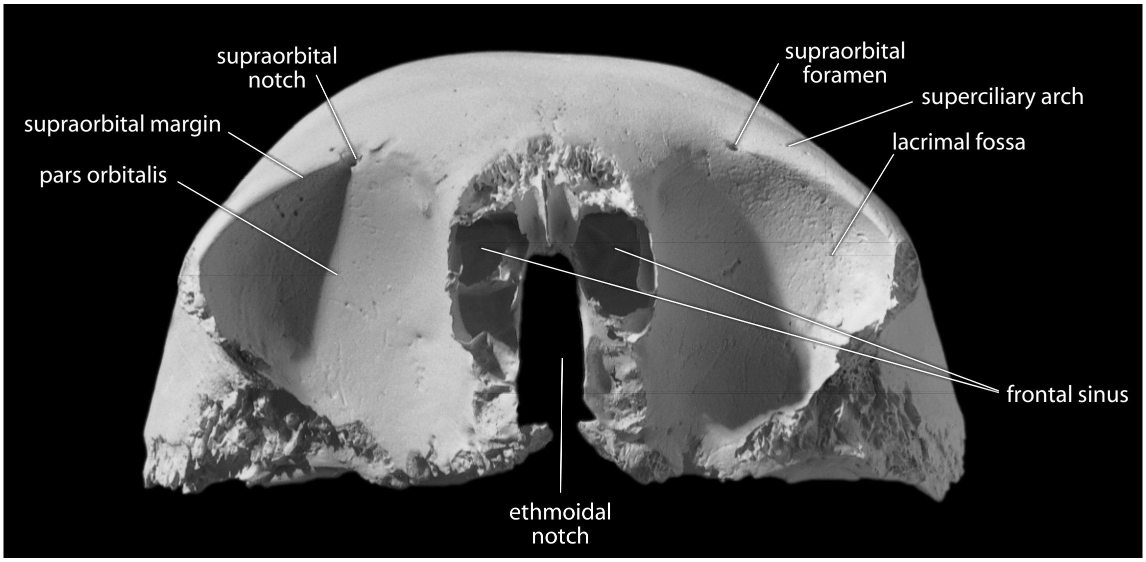


Figure 4.16 **Frontal, inferior (ectocranial)**. Natural size.

plates. Personal identification in forensic cases has been accomplished by employing radiographs of this region. Distinctive patterns of frontal sinuses can then be used for individuation.

4.7.2 Growth

The frontal ossifies intramembranously from two primary centers. At birth these centers are separate. They fuse along the metopic suture (midline), usually during a child's second year.

4.7.3 Possible Confusion

- When fragmentary, the frontal is confused most often with the parietals. The meningeal impressions are larger and more dense on the parietals, and the endocranial surfaces of the parietals are less undulating than those of the frontal.
- The frontal is the only major vault bone with a substantial sinus and adjacent orbital rims.

4.7.4 Siding

Isolated fragments of frontal squama may be difficult to side. Siding the frontal or any other bone or tooth, whether fragmentary or intact, is often simplified by holding the element in its correct orientation adjacent to that region of your own skull. In other words, attempt to imagine the fragment fitting into your own anatomy. The coronal suture is posterior and courses anterolaterally, toward the face, from bregma. This means that the sagittal and coronal sutures do not meet at right angles. This fact can be very useful in siding fragments of frontal squama.

- The anteromedially placed frontal sinus is often exposed in broken pieces.
- The ectocranially placed temporal lines swing medially and weaken posteriorly.

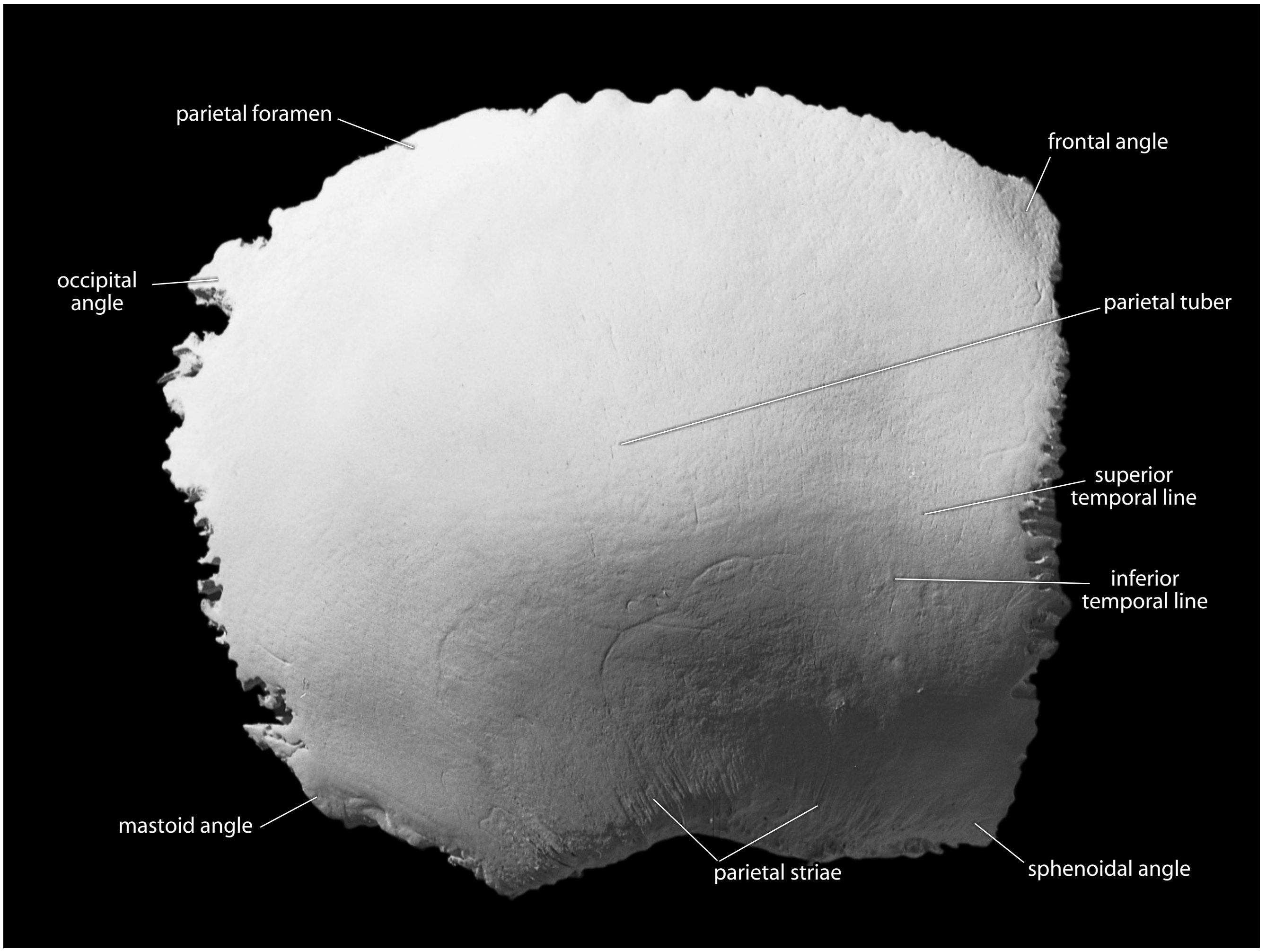
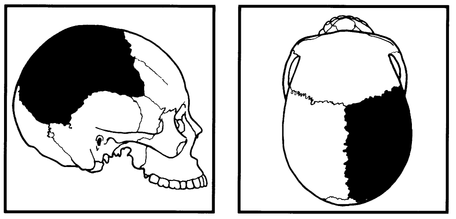


Figure 4.17 **Right parietal, lateral (or ectocranial)**. Anterior is toward the right, superior is up. Natural size. See Figure 4.1 for more strongly expressed temporal lines.



4.8 Parietals (Figures 4.17–4.18)

4.8.1 Anatomy

The parietals form the sides and roof of the cranial vault. Each parietal articulates with the opposite parietal and with the frontal, temporal, occipital, and sphenoid. Parietals are basically square and are the largest bones of the vault, with a fairly uniform thickness.

a. The **frontal angle** is located at bregma.

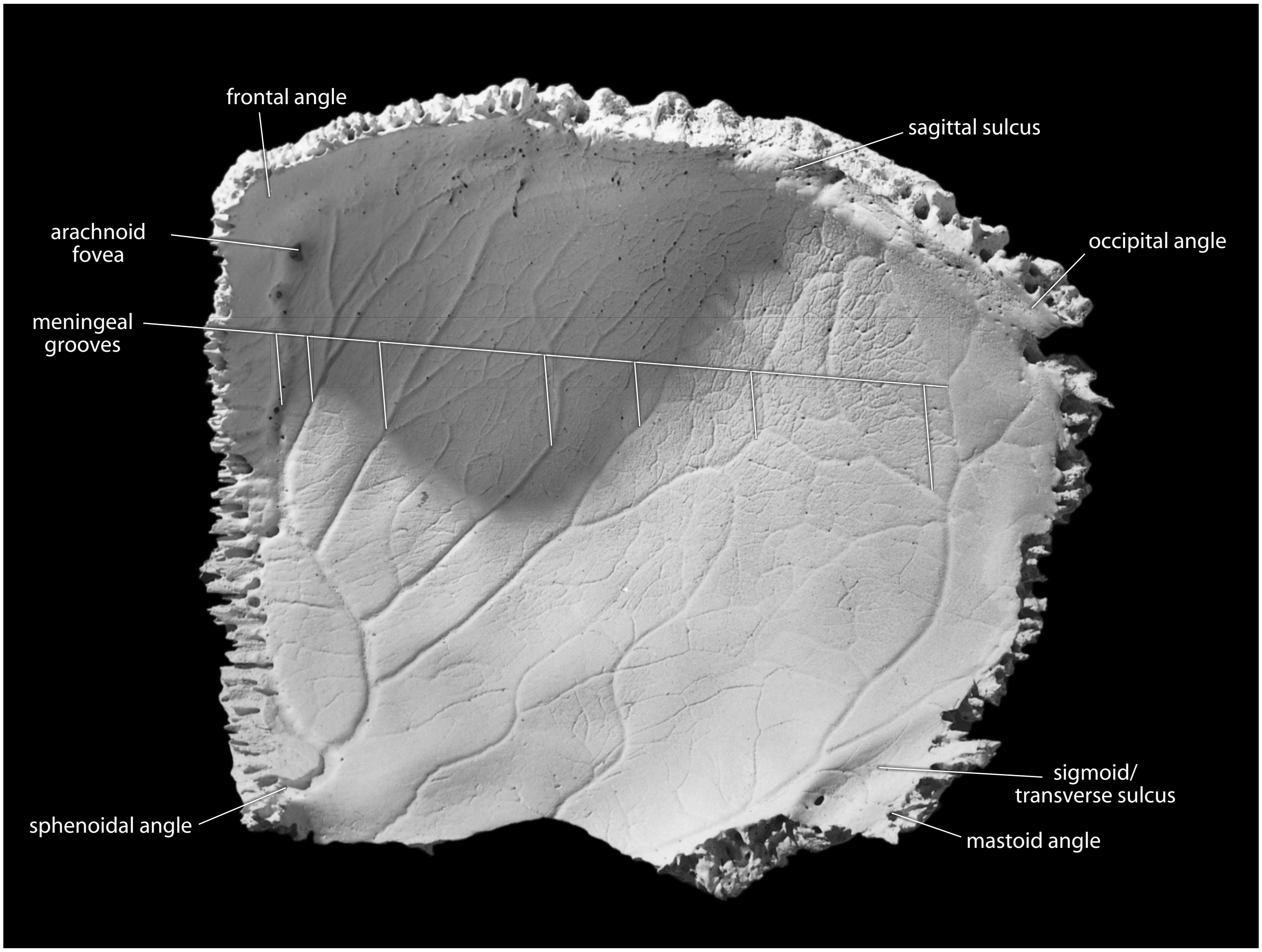


Figure 4.18 **Right parietal, medial (or endocranial).** Anterior is toward the left, superior is up. Natural size.

b. The **sphenoidal angle** is located at pterion.
c. The **occipital angle** is located at lambda.
d. The **mastoid angle** is located at asterion.
e. The **parietal tuber** (or **boss** or **eminence**) is the large, rounded eminence centered on the ectocranial surface of the parietal. It marks the center of ossification of the bone.
f. **Temporal lines** dominate the ectocranial surface, arching anteroposteriorly.
g. The **superior temporal line** anchors the *temporal fascia*.
h. The **inferior temporal line** indicates the most superior extent of the *temporalis muscle*.
i. When present, the **parietal foramen** is located close to the sagittal suture near lambda. It transmits a small vein through the parietal to the superior sagittal sinus.

j. The **parietal striae** are striations, or "rays," that pass posterosuperiorly for some distance on the ectocranial surface of the parietal from their origin on its beveled squamous edge.

k. **Meningeal grooves** for *middle meningeal arteries* dominate the endocranial surface of the parietal. These arteries supply the *dura mater*. The most anterior branch parallels the coronal edge of the parietal, and most of the branches traverse the bone toward its occipital angle.

l. The **sagittal sulcus** is made when the parietals are articulated and the shallow grooves along the sagittal edge of each parietal combine along the endocranial midline. This sulcus is a posterior continuation of the same feature on the frontal.

m. **Arachnoid** (or **granular**) **foveae** are concentrated endocranially along the anterior extent of the sagittal edge of each parietal. They are functionally equivalent to structures of the same name described for the frontal (Section 4.7.1n).

n. The **sigmoid sulcus** (or **sulcus for the sigmoid** and/or **transverse sinus**) crosses the mastoid angle of the parietal, cutting a groove on the endocranial surface. It marks the course of the *transverse* (or *sigmoid*) *sinus*, a vessel that drains blood from the brain.

4.8.2 Growth

The parietal bone ossifies intramembranously, with ossification extending radially from a combined center near the parietal boss. The four corners of the bone are not ossified at birth, and the remaining spaces are the fontanelles.

4.8.3 Possible Confusion

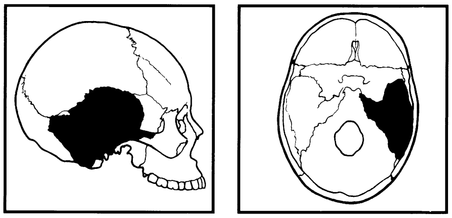
When fragmentary, the parietal is confused most often with the frontal, occipital, or temporal. The frontal, occipital, and temporal do not have parietal foramina, as many meningeal grooves, or ectocranial striae associated with an externally facing beveled suture (the squamous).

- The cross section of a parietal is more regular (thickness does not vary as much) than those of the other vault bones.
- The temporal line is a constant feature across the length of the parietal.
- The endocranial surface of this bone is not as undulating and irregular as that of the frontal or the occipital.

4.8.4 Siding

Siding is difficult only when the parietal bone is very fragmentary. The meningeal grooves are oriented vertically along the coronal suture and more horizontally near the squamous suture.

- The coronal suture, unlike the sagittal suture, is an interdigitating, rather than an interlocking, zipper-like, or jigsaw-like articulation. The large *anterior middle meningeal vessel* makes an impression along this suture endocranially.
- The thickest corners are the occipital and mastoid angles.
- The mastoid angle bears a sulcus endocranially.
- The squamous suture is lateral and inferior, and the parietal striae angle posterosuperiorly.



4.9 Temporals (Figures 4.19–4.21)

4.9.1 Anatomy

Temporals form the transition between cranial wall and base, house the delicate organs of hearing, and form the upper surface of the jaw joints. The highly irregular shape of the temporal is related to the varying functions of the bone. The temporal articulates with the parietal, occipital, sphenoid, zygomatic, and mandible. The jaw joint, or temporomandibular joint, is often abbreviated TMJ. Parts of the temporal bone are very robust and, for this reason, are often more resistant to destruction than other parts of the cranial vault.

a. The thin, plate-like **temporal squama** rises almost vertically to form the cranial walls and articulate with the parietals along the squamous suture.
b. The **petrous pyramid** (or **pyramidal process)** is the massive, dense bony part that dominates the endocranial aspect of the temporal. The sharp superior edge of the endocranial petrous surface angles anteromedially, separating the *temporal* and *occipital lobes* of the brain and housing the internal ear. The petrous is wedged between the occipital and the sphenoid. The end-on (anteromedial) view is into the carotid canal (Section 4.9.1v). This petrous part of the bone houses the delicate organs of hearing and equilibrium, including the tiny movable malleus, incus, and stapes bones.
c. The **external acoustic** (or **auditory**) **meatus** (**EAM**) is the external opening of the ear canal, which passes anteromedially for about 2 cm. The inner end of the canal is closed by the tympanic membrane (eardrum) in the living individual.
d. The **zygomatic process** of the temporal is a thin projection of bone that forms the posterior half of the zygomatic arch. Its anterior edge is the serrated zygomaticotemporal suture, its superior edge is an attachment for the *temporal fascia*, and its inferior edge anchors fibers of the *masseter muscle.*
e. The **suprameatal crest** is the superior root of the zygomatic process. It runs horizontally above the EAM where the craniometric point auriculare is located.
f. The **supramastoid crest** is the posterior extension of the suprameatal crest. The continuous raised edge of these crests marks the limit of the *temporalis muscle* and *temporal fascia* attachment.
g. The **parietal notch** is formed by the posterosuperior border of the temporal where the squamous and parietomastoid sutures meet.
h. The **mastoid process** bears an external surface that is roughened for the attachment of several muscles including the following: *sternocleidomastoideus, splenius capitis,* and *longissimus capitis*. These muscles function in extension, flexion, and rotation of the head. The *temporalis muscle* may also attach in this region when the supramastoid crest is present on the mastoid area, as in some humans and many fossil hominids. Internally, the thin-walled mastoid process is occupied by a number of variably developed voids known as **mastoid cells**.
i. The **mastoid foramen** (occasionally multiple) is located near the posterior edge of the mastoid process along the occipitomastoid suture. It transmits a small branch of the *occipital artery,* which supplies the dura mater, the diploë (spongy bone sandwiched between inner and outer bone tables of cranial vault bones), and the mastoid air cells.

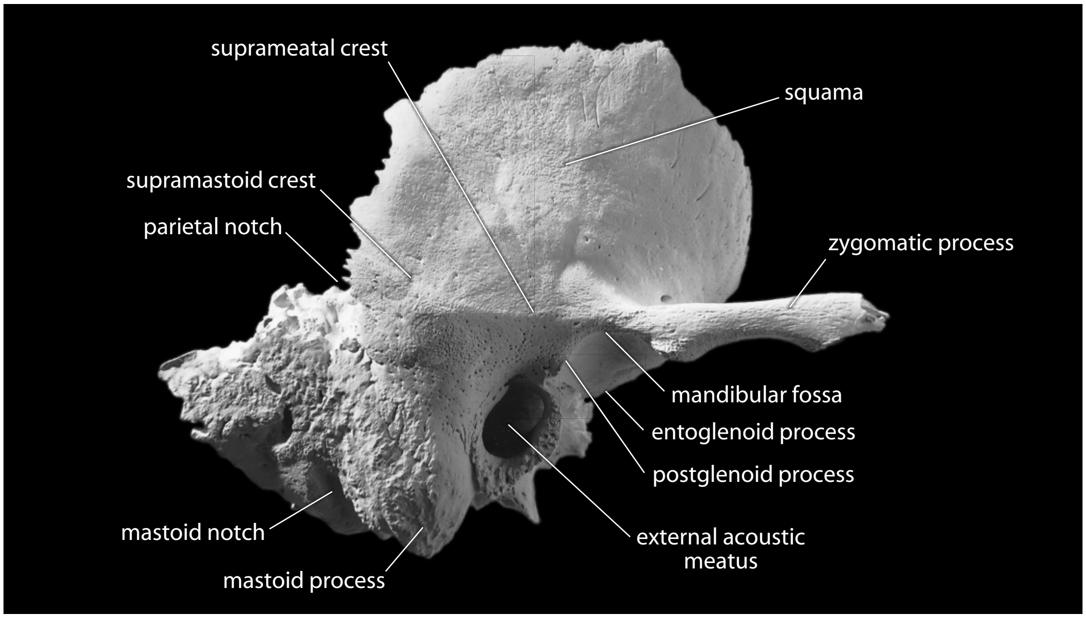


Figure 4.19 **Right temporal, lateral (ectocranial).** Anterior is toward the right, superior is up. Natural size.

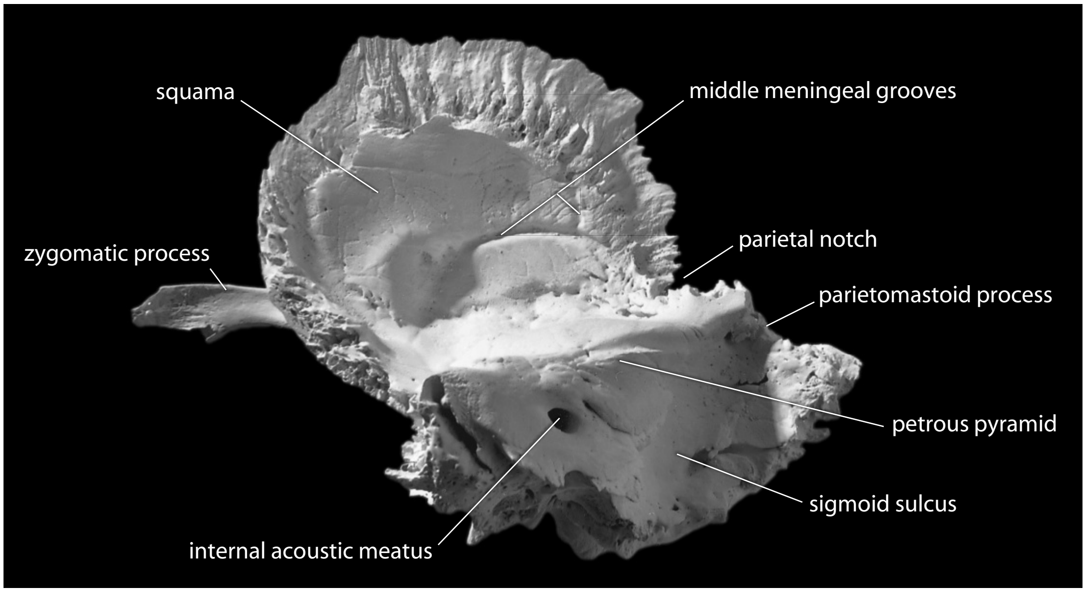


Figure 4.20 **Right temporal, medial (endocranial).** Anterior is toward the left, superior is up. Natural size.

j. The **mastoid notch** (or **digastric groove**) for attachment of the *digastric muscle* is the vertically oriented furrow medial to the mastoid process.

k. The **occipital groove** (or **sulcus**) lies just medial to the mastoid notch. It is a shallow furrow that lodges the *occipital artery*.

l. The **temporomandibular articular surface** is the smooth, articular surface inferior to the root of the zygomatic process. There is considerable topographic relief to this inferiorly facing surface.

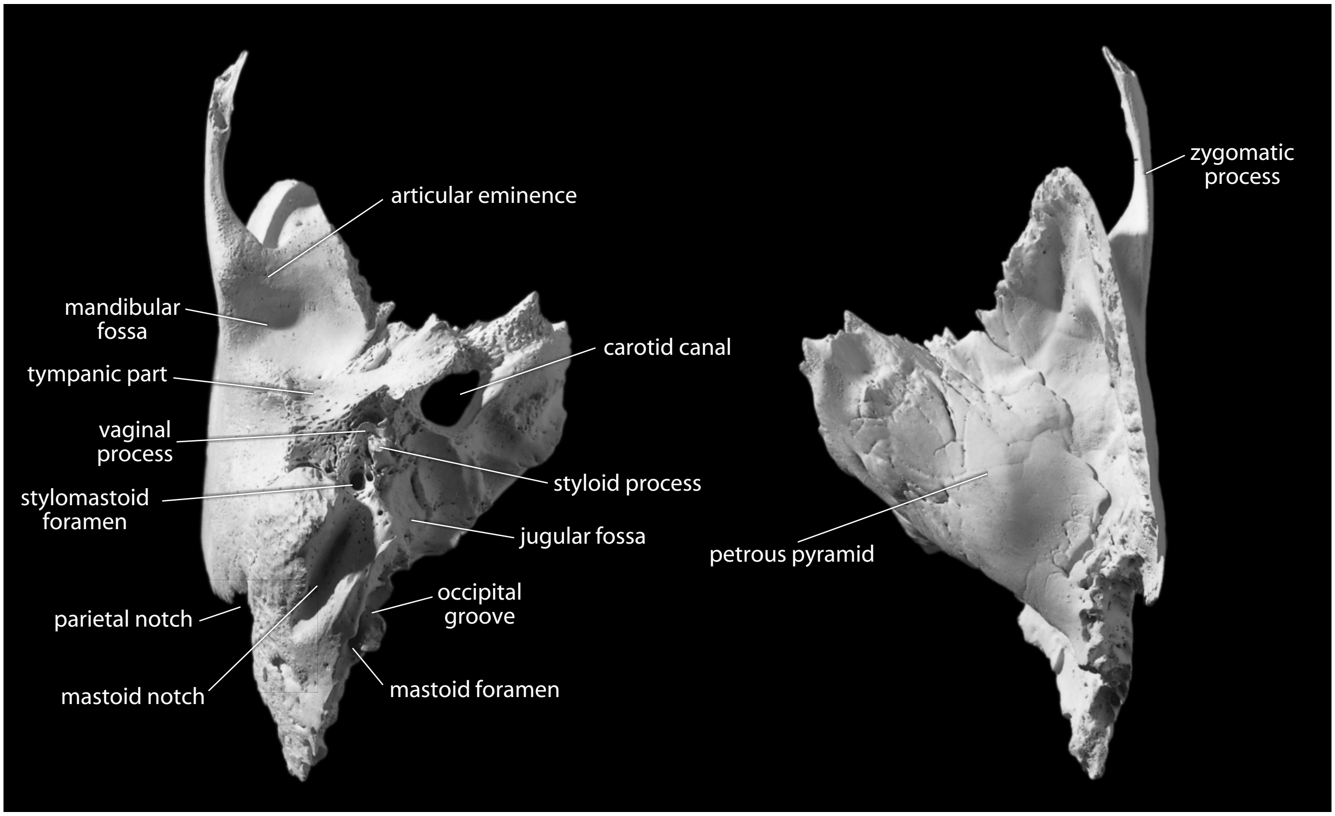


Figure 4.21 **Right temporal.** *Left:* inferior view, anterior is up, medial is to the right; *right:* superior view, anterior is up, medial is to the left. Natural size.

m. The **articular eminence** forms the anterior portion of the temporomandibular articular surface.

n. The **mandibular** (or **glenoid**) **fossa** lies posterosuperior to the articular eminence. The eminence and the fossa itself are bounded medially by the sphenosquamous suture. In chewing, the condyle of the mandible moves anteriorly onto the eminence and posteriorly into the fossa as well as from side to side in actions at the TMJ. In life there is a fibrocartilaginous *articular disk* interposed between the mandibular condyle and the fossa.

o. The **postglenoid process** is a projection that lies just anterosuperior to the EAM, interposed between the **tympanic part** of the bone (which forms most of the rim of the EAM) and the mandibular fossa. This rim is roughened for the attachment of the cartilaginous part of the EAM.

p. The **entoglenoid process** is the inferior projection of the articular surface at the medial edge of the articular eminence.

q. The **tympanic part** of the temporal lies posterior to the TMJ. Its anterior surface, forming the rear wall of the mandibular fossa, is nonarticular.

r. The **styloid process** is a thin, pointed bony rod that points anteroinferiorly from the base of the temporal bone. It is a slender projection of variable length and is fragile and often broken or missing (as on the illustrated specimen, where its distal end has snapped off). It anchors the *stylohyoid ligament* (sometimes partly ossified) and several small muscles.

s. The **stylomastoid foramen**, located immediately posterior to the base of the styloid

process, is for the exit of the *facial nerve* (cranial nerve 7) and the entrance of the *stylomastoid artery*.

t. The **vaginal process** ensheathes the base of the styloid process.

u. The **jugular fossa** is located just medial to the base of the styloid process. This deep fossa houses the *bulb of the internal jugular vein*, a vessel that drains blood from the head and neck.

v. The **carotid canal** is a large circular canal that transmits the *internal carotid artery*, a major source of blood for the head, and the *carotid plexus* of nerves. It is situated medial to the styloid process at the level of the sphenosquamous suture, just anterior to the jugular fossa.

w. **Middle meningeal grooves** are narrow, well-defined channels that mark the endocranial surface of the temporal. The larger, more diffuse undulations on this surface are related to convolutions of the *temporal lobe* of the brain.

x. The **internal acoustic** (or **auditory**) **meatus** is located about midway along the posterior surface of the petrous pyramid and transmits the *facial* and *acoustic nerves* (cranial nerves 7 and 8, respectively) as well as the *internal auditory artery*.

y. The **sigmoid sulcus** is the large, curving groove set at the posterior base of the petrous pyramid on the endocranial surface of the mastoid part of the temporal bone. This sulcus houses the *sigmoid sinus*, an anteroinferior extension of the *transverse sinus*, which is a major vessel draining blood from the brain into the *internal jugular vein*. Note that this sulcus is a continuation of the sulcus on the posteroinferior corner of the parietal.

4.9.2 Growth

Growth of the temporal is complex, with both membranous and endochondral ossification. It ossifies from eight centers during fetal development, not counting those of the middle ear or tympanic ring. As birth approaches, only three main centers remain: the squama, the petrous part, and the tympanic ring.

4.9.3 Possible Confusion

Even when fragmentary, it is difficult to confuse the temporal with other bones because of its unique morphology. The broken elements that may present some trouble are the squama and zygomatic process.

- The temporal squama overlaps the parietal. It is thinner than the parietal or frontal.
- Fragmentary temporal processes of the zygomatic bone are not as thin and long as the zygomatic process of the temporal.

4.9.4 Siding

- For isolated mastoid sections, the mastoid tip points inferiorly and the entire mastoid angles anteriorly.
- The mastoid notch (or digastric groove) is posterior and medial.
- For isolated petrous pyramids, the internal acoustic foramen is posterior and the pyramid tapers anteromedially.
- For isolated fragments of squama, the squamous suture surface overlaps the ectocranial surface of the parietal. Grooves for the middle meningeals branch posteriorly and slightly superiorly.

- For broken zygomatic processes, the articular eminence is posterior, the superior edge of the arch is thinnest, and the zygomaticotemporal suture runs from posteroinferior to anterosuperior.

4.10 Auditory Ossicles (Figure 4.22)

The tiny ear ossicles, the **malleus** (hammer), **incus** (anvil), and **stapes** (stirrup), are housed in the tympanic cavity of the temporal. The first is connected to the *tympanic membrane,* or *eardrum*, and the others are located more medially. These bones are so small that they are best observed under magnification. They are often lost during skeletal recovery and are seldom studied.

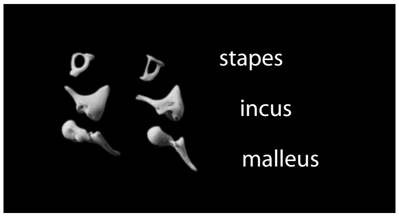
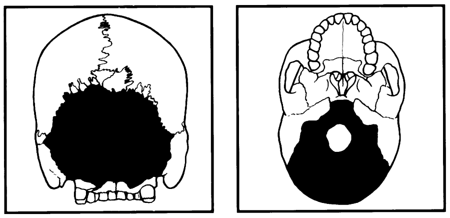


Figure 4.22 **Auditory ossicles viewed from both sides**. Natural size.

4.11 Occipital (Figures 4.23–4.24)



4.11.1 Anatomy

The occipital bone is set at the rear of the cranium and articulates with the temporals, sphenoid, parietals, and the uppermost vertebra, the atlas.

a. The **foramen magnum** is the large hole in the occipital through which the *brainstem* passes inferiorly into the vertebral canal.
b. The **squamous** portion of the occipital bone is by far the largest, constituting the large plate of bone posterior and superior to the foramen magnum.
c. The **occipital planum** is that part of the occipital squama that lies above the superior nuchal lines (Section 4.11.1e). The section of squama inferior to the lines is the **nuchal planum**.
d. The **external occipital protuberance** lies on the ectocranial midline where the occipital and nuchal planes meet. It is highly variable in appearance and heavier and more prominent in male individuals.
e. **Superior nuchal lines** lie to either side of the midline on the ectocranial surface of the squamous portion. The nuchal plane and occipital planes merge at these superiorly convex lines. Several *nuchal muscles* attach to and below these lines and function to extend and rotate the head.

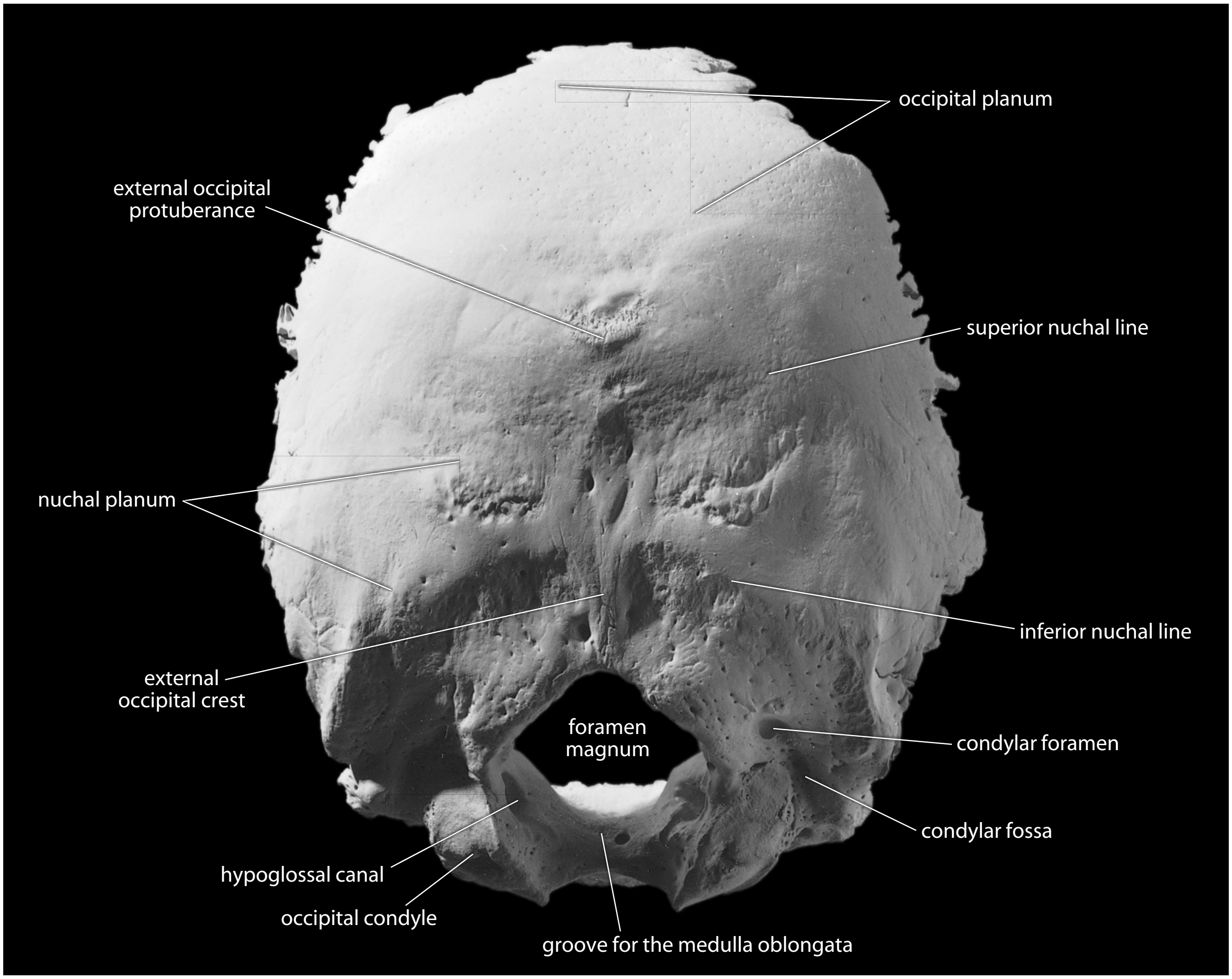


Figure 4.23 **Occipital, posteroinferior (ectocranial).** Superior is up. Natural size.

f. **Inferior nuchal lines** parallel the superior lines but are located about midway on the ectocranial nuchal plane. Fascia separating *nuchal muscles* attach to the line, whereas additional *nuchal muscles* attach inferior to this line.

g. The **external occipital crest** (or **median nuchal line**) is a highly variable median line or crest that passes between the right and the left *nuchal musculature*. It stretches from the external occipital protuberance to the rear of the foramen magnum, anchoring the *nuchal ligament*.

h. The **basilar part** is the thick, square projection anterior to the foramen magnum. This part articulates with the petrous portions of both temporals and with the sphenoid via the basilar (or sphenooccipital) suture.

i. The **lateral** (or **condylar**) **parts** of the occipital lie to either side of the foramen magnum, articulating with the temporals.

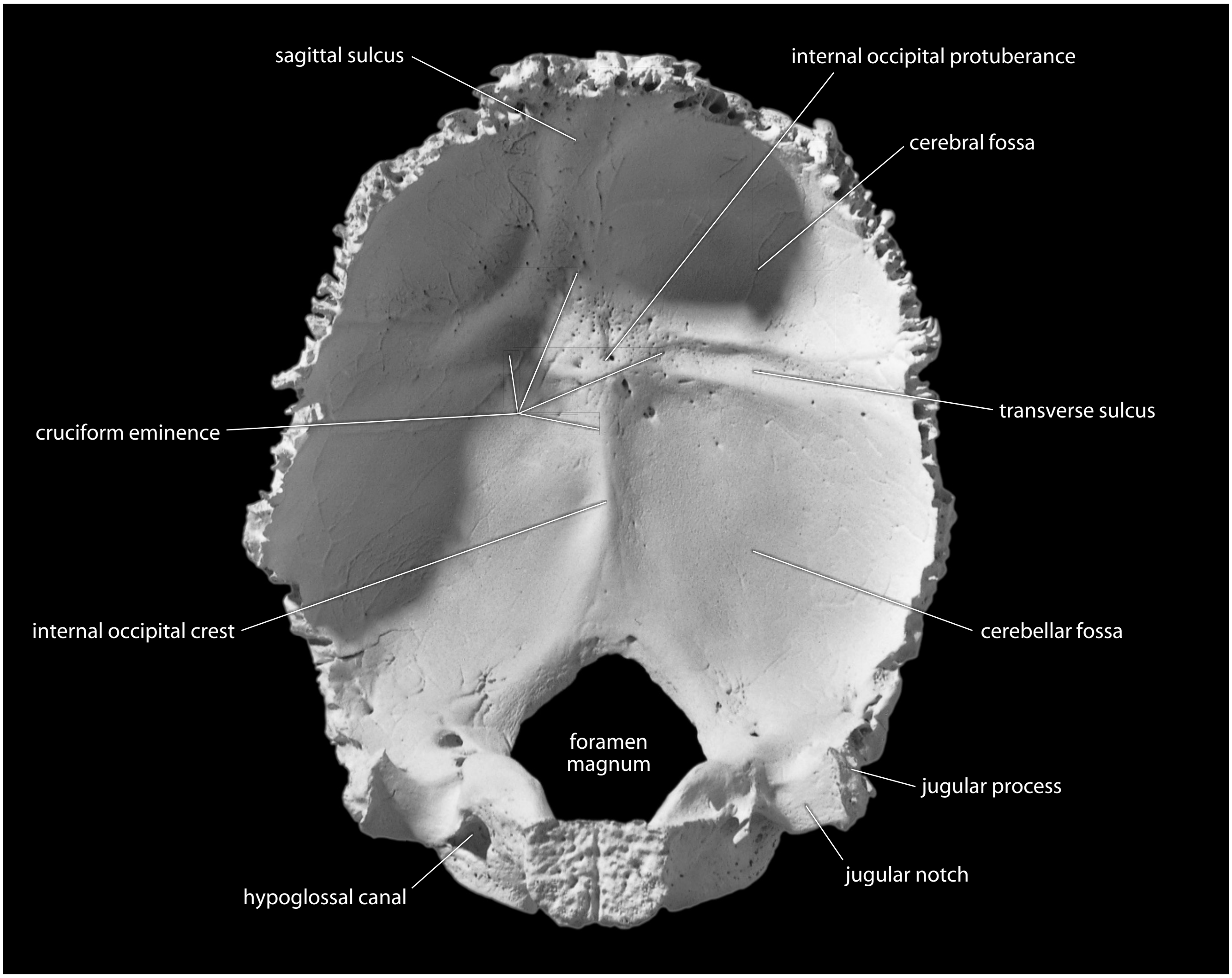


Figure 4.24 **Occipital, anterior (endocranial).** Superior is up. Natural size.

j. **Occipital condyles** are raised oval structures on either side of the foramen magnum. Their inferior surfaces are convex. The articular surfaces of these condyles fit into the concave facets of the atlas vertebra.

k. **Condylar fossae** are ectocranial depressions immediately posterior to the condyles. These fossae receive the posterior margin of the superior facet of the atlas vertebra when the head is extended backward.

l. **Condylar foramina** (and **canals**) perforate the occipital at the depth of the condylar fossae, where each transmits an *emissary vein*.

m. **Hypoglossal canals** are tunnels through the anterior part of the base (therefore superior in placement) of each condyle. These canals give exit to *hypoglossal nerves* (cranial nerve 12) and entrance to arteries.

n. **Jugular processes** are laterally directed corners of the bone placed lateral to the condyles. The tips of these processes lie at the anteriormost point along the occipitomastoid suture.

o. The **jugular notch** is excavated into the anterior surface of the jugular process. This notch forms the posterior half of the jugular foramen in the articulated cranium, with the anterior half being contributed by the temporal bone (Section 4.9.1u).
p. The **cruciform eminence** divides the endocranial surface of the occipital squama into four fossae. It is so named because it is cross-shaped.
q. **Cerebral fossae** are triangular depressions below the lambdoid suture on the endocranial surface of the occipital. They house the *occipital lobes* of the brain's *cerebrum*.
r. The **cerebellar fossae** occupy the inferior part of the endocranial surface of the occipital squama. Therein rest the *cerebellar lobes* of the brain.
s. The **internal occipital protuberance** lies at the center of the cruciform eminence.
t. The **sagittal** (or **occipital**) **sulcus** passes superiorly from the internal occipital protuberance. It is a deep endocranial groove marking the posterior extension of the *sagittal sinus*, a major blood drainage pathway from the brain.
u. The **internal occipital crest** is the inferior arm of the cruciform eminence. Sometimes it bears a sulcus that continues on one or both sides of the foramen magnum. Such a sulcus, called an **occipitomarginal sulcus**, represents an alternative pathway for blood to drain from the brain.
v. **Transverse sulci** form the transverse arms of the cruciform eminence. They house the *transverse sinuses*. The one on the right is usually larger and communicates directly with the sagittal sulcus. However, variations in the soft tissue and bony manifestations of this cranial venous drainage system are common and sometimes pronounced. The transverse sulcus of the occipital connects with the sigmoid sulcus of the temporal and endocranial jugular process, often via the transverse (or sigmoid) sulcus on the mastoid angle of the parietal.
w. The **groove for the medulla oblongata** is the hollowing on the endocranial surface of the basilar part of the occipital, the clivus.

4.11.2 Growth

The occipital is another bone with both membranous and endochondral ossification. At birth the occipital consists of four parts: the squama, the lateral parts that bear the condyles, and the basilar part. The squamous and lateral portions unite at about age 4, and by age 6 the basilar part attaches to these. The synostosis (fusion) between the occipital and the sphenoid (across the sphenooccipital synchondrosis) normally takes place between 18 and 25 years of age.

4.11.3 Possible Confusion

Even when fragmentary, the occipital is difficult to confuse with other bones of the vault.

- There is wide variation in thickness across the occipital squama that is not found in the parietals or the frontal.
- The occipital lacks meningeal grooves endocranially and has much more ectocranial rugosity than seen on the parietal or frontal.

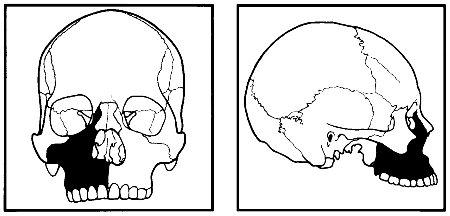
Other possible confusion may come when extrasutural bones are encountered. These bones are sometimes quite large, particularly along the lambdoid suture. One even has a name, the **inca bone**. This is a large, triangular, symmetrical bone placed at the top of the occipital, just below lambda.

4.11.4 Siding

Isolated fragments of the occipital are easily sided by locating the lambdoid suture.

- For isolated condyles, the edge of the foramen magnum is medial and somewhat posterior to the condylar body centers.
- The condylar fossa is posterior, and the hypoglossal canals tunnel from anterolateral to posteromedial.

4.12 Maxillae (Figure 4.25)



4.12.1 Anatomy

Maxillae are a pair of bones that form the dominant portion of the face. Functionally, the maxillae hold the tooth roots and form most of the nasal aperture and floor, most of the hard palate, and the floors of the orbits. Most of the maxillary bone is light and fragile, the exception being the portion that holds the teeth. Maxillae comprise four basic processes. They articulate with each other and with the frontal, nasals, lacrimals, ethmoid, inferior nasal conchae, palatines, vomer, zygomatics, and sphenoid.

a. The **alveolar process** is the horizontal portion of the maxilla that holds the tooth roots.
b. **Alveoli** for the tooth roots are present all along the alveolar process, except where these have been resorbed following the loss of teeth.
c. The **canine jugum** is a bony eminence over the maxillary canine root on the facial surface of the maxilla.
d. The **zygomatic process** forms much of the cheek.
e. The **infraorbital foramen** is located below the inferior orbital rim on the facial surface and transmits the *infraorbital nerve* (a division of cranial nerve 5) and *vessels* to the face.
f. The **canine fossa** is a hollow of variable extent located on the facial surface just below the infraorbital foramen, where the zygomatic, frontal, and alveolar processes of the maxilla come together.
g. The **anterior nasal spine** is the thin projection of bone on the midline at the inferior margin of the nasal aperture.
h. The **infraorbital sulcus** (or **groove**) is centered on the posterior half of the orbital floor and opens posterosuperiorly. It connects anteroinferiorly with the infraorbital foramen via the **infraorbital canal**.
i. The **maxillary sinus** is the large void in the body of the maxilla, superior to the alveolar process and inferior to the orbital floor.
j. The **frontal process** rises to articulate with the frontal, nasals, lacrimal, and ethmoid.
k. The **anterior lacrimal crest** is a vertical crest located on the lateral aspect of the frontal process of the maxilla, and marking the anterior extent of the **lacrimal groove**. The lacrimal

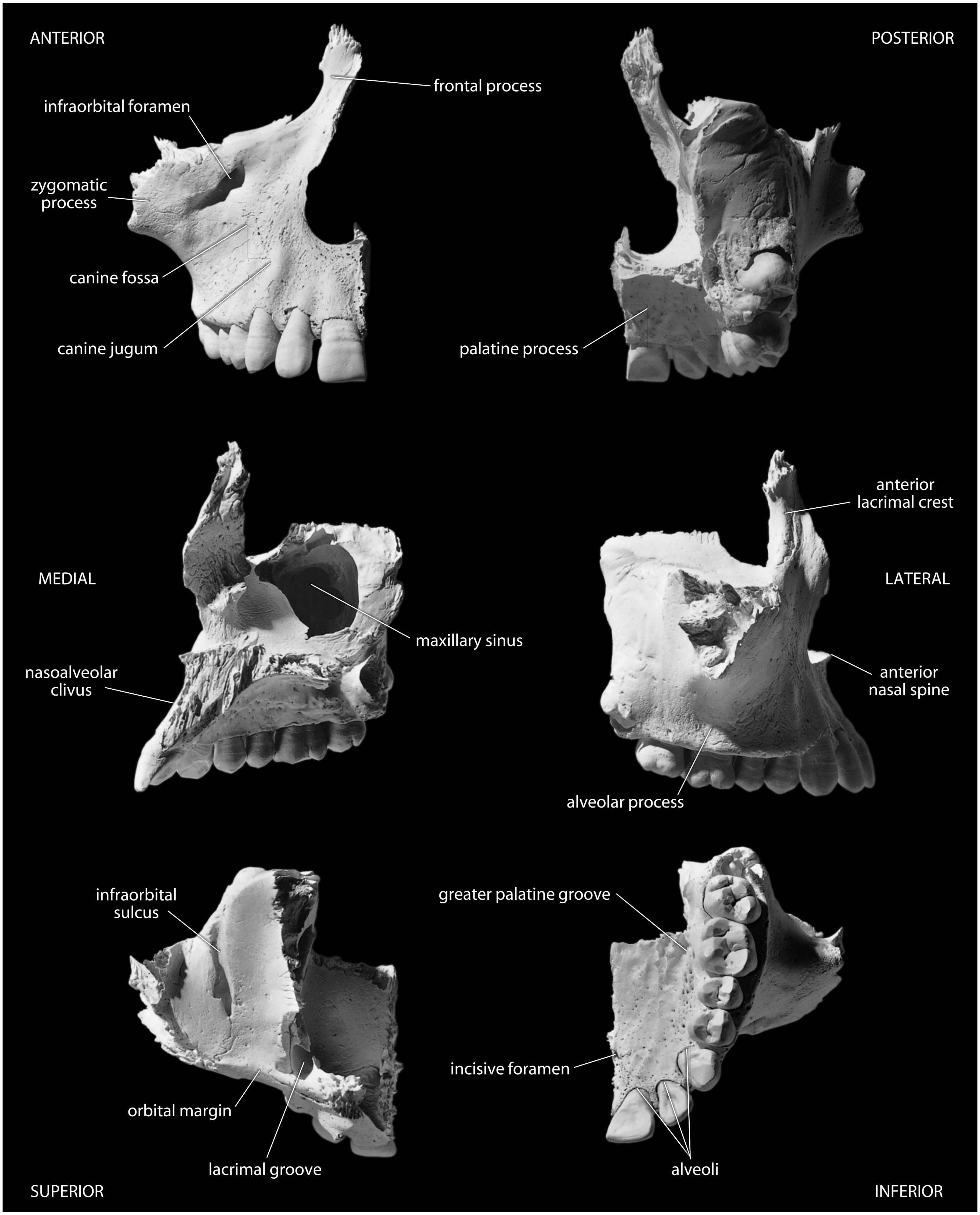


Figure 4.25 **Right maxilla.** Natural size.

groove of the maxilla combines with the lacrimal bone to form the **lacrimal canal**. This canal houses the *nasolacrimal duct,* which drains tears inferiorly into the nasal cavity.

l. The **palatine process** forms the anterior two-thirds of the hard palate and floor of the nasal cavity.

m. The **incisive foramen** perforates the anterior hard palate at the midline.

n. The **incisive canal** is bilobate, opening via the incisive foramen, with each lobe enclosed by one of the maxillae. Each lobe of the canal transmits the *terminal branch of the greater palatine artery* and the *nasopalatine nerve*.

o. The **premaxillary suture** is sometimes seen in the wall of the incisive canal and on the adjacent palatal surface, particularly in young individuals.

p. The **greater palatine groove** at the rear of the hard palate marks the junction of the palatine and alveolar processes. This groove is for the *greater palatine vessels* and *nerve*.

q. The **maxillary tuber** is the rugose surface at the posterior end of the alveolar process. It is variable in expression, articulating with the pyramidal process of the palatine and sometimes with the lateral pterygoid plate of the sphenoid.

r. The **nasoalveolar clivus** is the surface between the canine jugae, the base of the piriform aperture, and the alveolar margin.

4.12.2 Growth

Each maxilla ossifies from two main combined centers, one for the maxilla proper and one for the premaxilla. These fuse early in human development, about the ninth week *in utero*, but the suture between them may persist into adulthood in the region adjacent to the incisive canal.

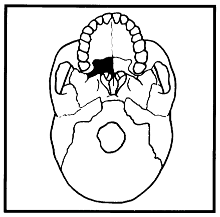
4.12.3 Possible Confusion

Small fragments of maxilla might be confused with other cranial bones. Because the bone is complex, it is helpful to note the diagnostic features useful in identifying it. These include the alveolar region, the sharp edges of the nasal aperture, the edge of the lacrimal canal, the large maxillary sinus, and the unique, serrated intermaxillary suture.

4.12.4 Siding

Fragments of maxilla may prove difficult to side and the use of comparative specimens may prove necessary.

- For a broken frontal process, the thinner edge is anterior and medial, the medial surface is vascularized (perforated by blood vessels), and the anterior lacrimal crest is lateral.
- For any segment with alveolar bone preserved, tooth roots or sockets can be used as a guide to medial, lateral, anterior, and posterior.



4.13 Palatines (Figure 4.26)

4.13.1 Anatomy

The small, delicate, L-shaped palatine bones form the rear of the hard palate and part of the wall and floor of the nasal cavity. Individual palatine bones are almost never found in an isolated, intact state; they generally accompany the maxillae and sphenoid, to which they are tightly bound. In addition to these two, palatines articulate with the vomer, inferior nasal conchae, ethmoid, and with each other.

a. The **horizontal plate** of the palatine forms the posterior third of the hard palate.
b. The **greater palatine foramen** (or **canal**) perforates the rear corner of the hard palate and is formed as the alveolar process of the maxilla meets the horizontal plate of the palatine. This canal transmits the *greater palatine vessels* and *nerve*.

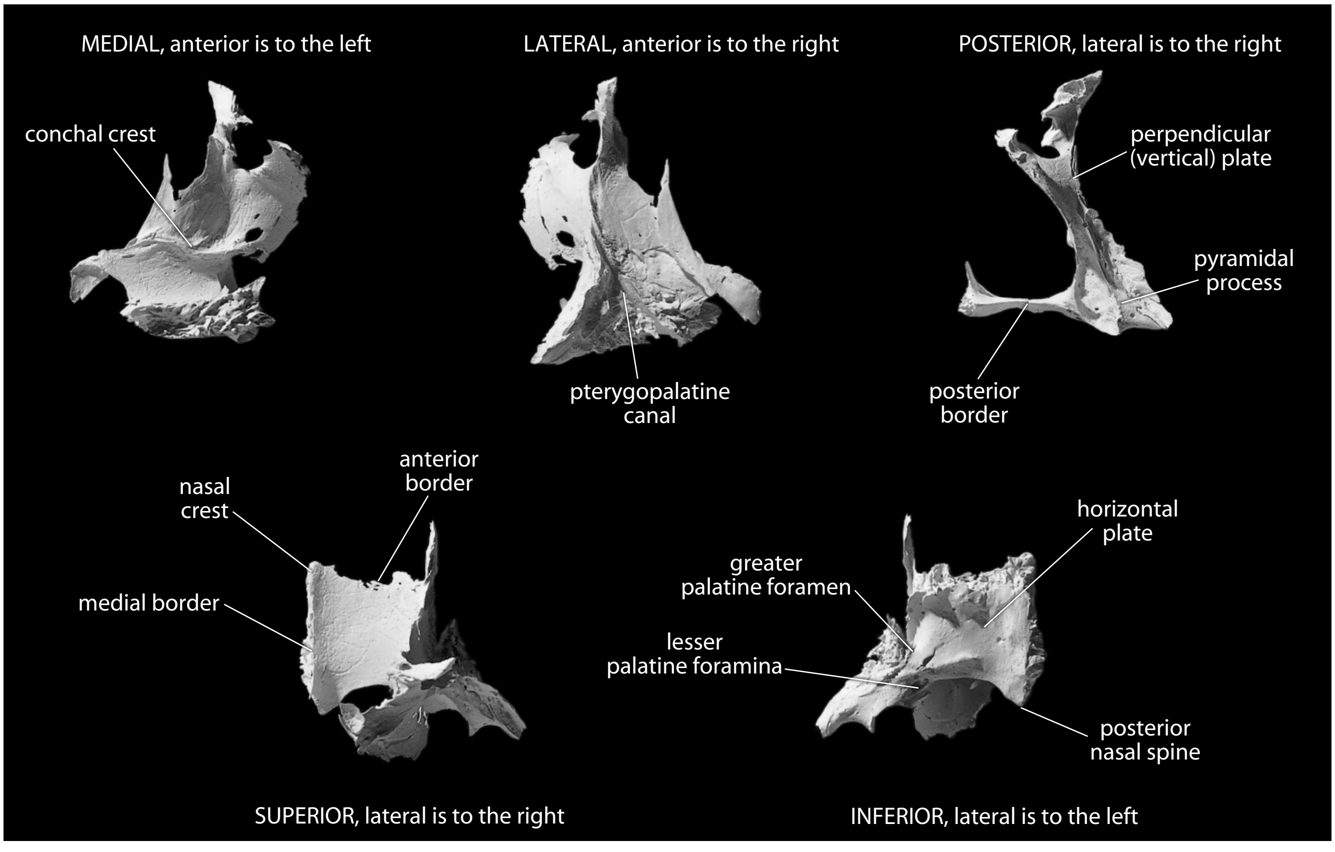


Figure 4.26 **Right palatine.** Natural size.

c. The two halves of the **pterygopalatine canal** become visible, sweeping posterosuperiorly, when the maxilla and perpendicular plate of the palatine are disarticulated.

d. The **posterior nasal spine** is located on the superior surface of the horizontal plate. The superior, or nasal cavity, surface of the plate is smoother and more regular than the palatal surface.

e. **Lesser palatine foramina**, for the transmission of *lesser palatine nerves*, are located on the posterolateral corner of the hard palate posterior to the greater palatine foramina, near the junction of the perpendicular and horizontal plates.

f. The **perpendicular** (or **vertical**) **plate** is appressed tightly to the posteromedial wall of the maxilla opposite the maxillary sinus, between the pterygoid plates of the sphenoid and the posterior margin of the alveolar process of the maxilla.

g. The posterior border of the perpendicular plate is the thickest border. It bears a serrated groove that articulates with the medial pterygoid plate of the sphenoid. This area of the bone is called the **pyramidal process**.

h. The **conchal crest** is a subhorizontally oriented crest placed not quite halfway up the perpendicular plate on the medial surface of the plate. This crest is for articulation with the inferior nasal concha.

4.13.2 Growth

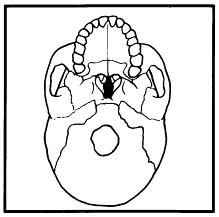
Palatine bones ossify intramembranously from single centers.

4.13.3 Possible Confusion

Because the palatines are almost always attached to the maxillae and sphenoid, identification is not usually difficult. When small, isolated fragments of palatine are encountered, note the free posterior edge of the horizontal plate and the smooth, even concavity on the nasal surface of this plate.

4.13.4 Siding

Because isolated fragments of palatine most often preserve the horizontal plate, note that the superior surface is smooth, that the inferior (palatal) surface is rough, that the posterior edge is nonarticular, and that greater and lesser palatine foramina are posterolateral.



4.14 Vomer (Figure 4.27)

4.14.1 Anatomy

The vomer is a small, thin, plow-shaped, midline bone that occupies and divides the nasal cavity. It articulates inferiorly on the midline with the maxillae and the palatines, superiorly with the sphenoid via its wings, and anterosuperiorly with the ethmoid. Thus, the bone forms the posteroinferior part of the nasal septum, which divides the nasal cavity.

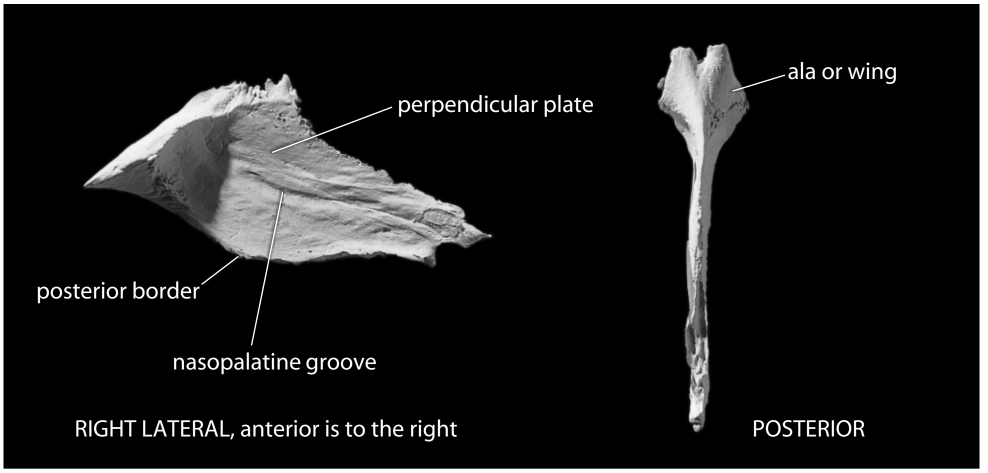


Figure 4.27 **Vomer.** Superior is up. Natural size.

a. **Alae**, or **wings**, of the vomer are located on either side of a deep midline furrow on the superior surface of the vomer. This part of the bone is the thickest and sturdiest and is tightly appressed to the sphenoid.
b. The **perpendicular plate** of the vomer is a thin vertical sheet of bone on the midline below the wings.
c. The nonarticular **posterior border** of the vomer divides the posterior nasal aperture into two halves.
d. **Nasopalatine grooves** lodge *nasopalatine nerves* and *vessels*, marking both sides of the perpendicular plate, where they run anteroinferiorly from the alae.

4.14.2 Growth

Another bone with both endochondral and membranous ossification, the vomer ossifies from two plates (laminae) on either side of a median plate of cartilage. By puberty, the lamellae are virtually united, but the bilaminar origin of the bone is discernible in the cleft between the alae.

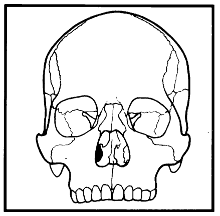
4.14.3 Possible Confusion

Because of the midline placement of the vomer, symmetry is the best guide to identification. Isolated vomers are rarely found and almost never recovered intact. To avoid confusion with other thin bones, such as the sphenoid, note that the vomer has alae and that the perpendicular plate is symmetrical, with a free posterior edge.

4.14.4 Siding

The nonmidline portions of the vomer are so small that siding criteria are unnecessary for this bone.

4.15 Inferior Nasal Conchae (Figure 4.28)



4.15.1 Anatomy

Inferior nasal conchae extend horizontally along the lateral walls of the nasal cavity, articulating with the medial wall of the maxillae and with the palatines. They also articulate with the ethmoid and lacrimals superiorly. The bones are rarely found isolated because they are so fragile. Their shape is variable, with the anterior and posterior extremities tapered to a point, and the inferior surface free, thickened, and vascularized. Inferior nasal conchae function in olfaction and in humidifying inhaled air.

a. The **maxillary process** of the inferior nasal concha is the delicate hook of bone extending towards the medial surface of the maxilla.
b. The **lamina** of the inferior nasal concha is a thin, vertical, undulating sheet of bone extending medially and inferiorly from the maxillary process.
c. The **lacrimal process** of the inferior nasal concha extends superiorly to contribute to the medial wall of the inferior lacrimal canal.
d. The **ethmoidal process** of the inferior concha is just posterior to the lacrimal process.

4.15.2 Growth

The inferior nasal conchae ossify from single centers.

4.15.3 Possible Confusion

Because inferior nasal conchae are so fragile, they are virtually never found intact as isolated specimens. Small fragments might be mistaken for ethmoid, sphenoid, or lacrimal. Note, however, that the surface texture of the inferior nasal conchae is highly perforated by numerous tiny apertures, giving them a fragile and lightweight aspect.

4.15.4 Siding

There is little use for knowledge of siding inferior nasal conchae.

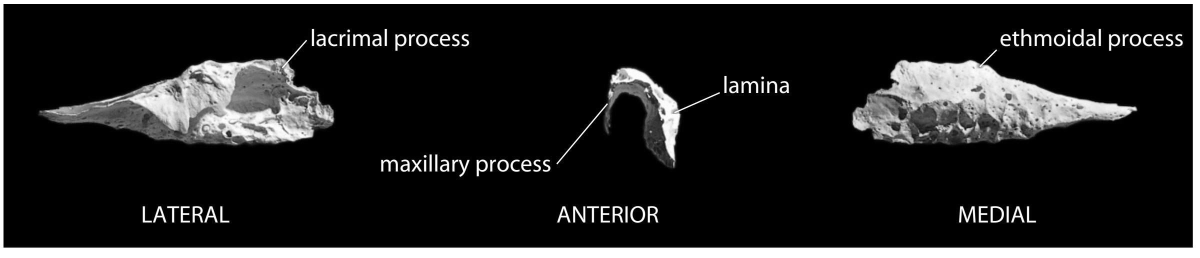
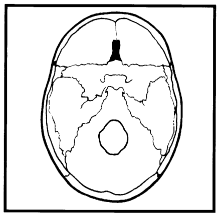


Figure 4.28 **Right inferior nasal concha.** *Left:* lateral view, anterior is to the right, superior is up; *middle:* anterior view, lateral is to the left, superior is up; *right:* medial view, anterior is to the left, superior is up. Lit from the upper right for detail. Natural size.

4.16 Ethmoid (Figure 4.29)



4.16.1 Anatomy

The ethmoid bone is exceedingly light and spongy. It is roughly the size and shape of an ice cube, but is only a fraction as heavy. It is located between the orbits, centered on the midline. It articulates with 13 bones: the frontal, sphenoid, nasals, maxillae, lacrimals, palatines, inferior nasal conchae, and vomer. The ethmoid is virtually never found as a unit because of its fragility. It is best viewed in a specially disarticulated skull, where its complexity can be appreciated.

a. The **cribriform plate** is best observed endocranially, where the ethmoid can be seen to fill the ethmoidal notch of the frontal. The cribriform plate roofs the nasal cavities, and because it is perforated by many tiny foramina it looks like a sieve. *Olfactory nerves* (cranial nerve 1) perforate this plate as they pass up to the brain from the mucous lining of the nose.
b. The **crista galli** is a perpendicular projection of the cribriform plate of the ethmoid into the endocranial cavity. It is interposed between *olfactory bulbs*, and its posterior surface anchors the *falx cerebri*, a fold of the *dura mater* extending into the longitudinal fissure of the brain between the two *cerebral hemispheres*.
c. The **labyrinths**, or **lateral masses**, of the ethmoid lie to either side of the midline and consist of a series of thin-walled ethmoidal cells. The lateral plates of the ethmoidal labyrinths form most of the medial orbital walls, and the medial plates form the upper walls of the nasal cavity.
d. The **perpendicular plate** of the ethmoid is a flattened lamina placed at the midline between the lateral masses. It forms part of the nasal septum and articulates inferiorly with the vomer.

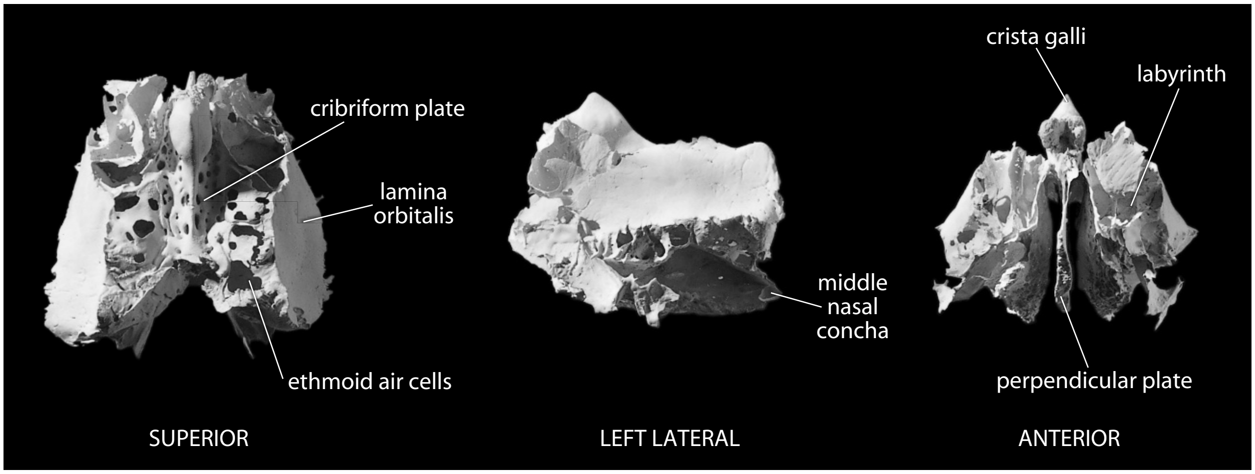


Figure 4.29 **Ethmoid.** *Left:* superior view, anterior is up; *middle:* left lateral view, anterior is to the left; *right:* anterior view, superior is up. Natural size.

4.16.2 Growth

The ethmoid is the only basicranial bone that is entirely preformed in cartilage. It ossifies from three centers, one for each labyrinth and one for the perpendicular plate. During the first year after birth, the perpendicular plate and crista galli begin to ossify. They are joined in the second year to the labyrinths.

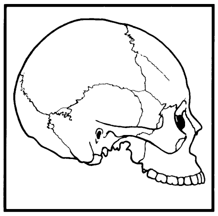
4.16.3 Possible Confusion

The thin plates of the ethmoid might be difficult to identify when found isolated, but this bone is rarely found by itself. More often, pieces of it adhere to the other bones it articulates with, most commonly the frontal or sphenoid. The perpendicular plate might be confused with the vomer, but the vomer has a nonarticular posterior edge and a thickened edge where the alae join.

4.16.4 Siding

The portions of ethmoid that are usually found isolated are both midline structures—the crista galli and the perpendicular plate.

4.17 Lacrimals (Figure 4.30)



4.17.1 Anatomy

The lacrimals are very small, thin, fragile bones of rectangular shape. The lacrimals make up part of the medial walls of the orbits anterior to the ethmoid. They articulate with the frontal, maxillae, ethmoid, and inferior nasal conchae. They are virtually never found alone but are often attached to facial fragments. The lacrimals have orbital and nasal (lateral and medial) surfaces and four borders.

a. The **posterior lacrimal crest** is a vertical crest on the medial orbital wall that bounds the posterior half of the lacrimal groove.

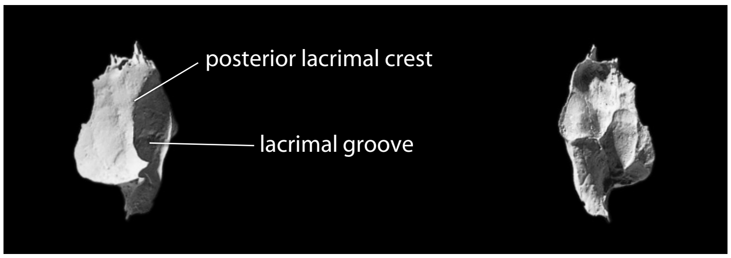


Figure 4.30 **Right lacrimal.** *Left:* lateral view, anterior is to the right, superior is up; *right:* medial view, anterior is to the left, superior is up. Natural size.

b. The **lacrimal groove** (or **sulcus**) forms the posterior portion of the superior end of the lacrimal canal.

4.17.2 Growth

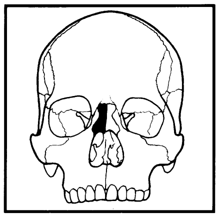
The lacrimal ossifies intramembranously from a single center.

4.17.3 Possible Confusion

The lacrimal crest is diagnostic, and although the lacrimal is virtually never found alone, it can often help to identify adjacent bones.

4.17.4 Siding

The posterior lacrimal crest is oriented vertically, and the lacrimal groove is anterior to the crest. The base of the crest sweeps anteriorly to become a margin for the lacrimal canal.



4.18 Nasals (Figure 4.31)

4.18.1 Anatomy

The nasals are small, thin, rectangular bones placed on either side of the midline below the glabellar region of the frontal. Their free inferior ends form the top margin of the anterior nasal aperture. The nasals articulate with the frontal superiorly, with each other medially, and with the frontal processes of the maxillae laterally. They articulate posteriorly with the ethmoid.

a. The **nasal foramen** perforates the facial surface and transmits a vein.

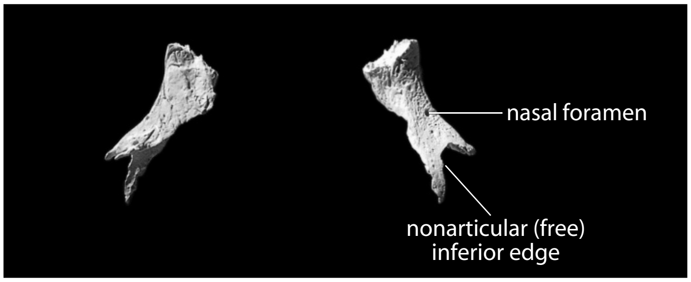


Figure 4.31 **Right nasal.** *Left:* medial view, anterior is to the left, superior is up; *right:* lateral view, anterior is to the right, superior is up. Natural size.

4.18.2 Growth

Each nasal ossifies intramembranously from a single center.

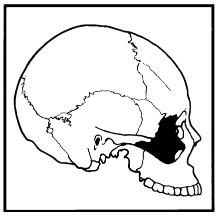
4.18.3 Possible Confusion

It is difficult to confuse the nasal with other bones because of its diagnostic internasal suture, the external foramen and internal groove, the smooth outer and rough inner surface, and the nonarticular, free inferior edge.

4.18.4 Siding

Use the criteria mentioned in Section 4.18.1 to side nasal bones.

- The free edge is inferior, the thickest articular edge is medial, and the frontonasal suture is interdigitating and superior.



4.19 Zygomatics (Figure 4.32)

4.19.1 Anatomy

Zygomatics form the prominent corners (cheeks) of the face. The edges are easily identifiable, with the rounded orbital rim, the sharp area around jugale adjacent to the temporal fossa, and the roughened inferior border. Each zygomatic bone articulates, via its three main processes, with the frontal, sphenoid, temporal, and maxilla.

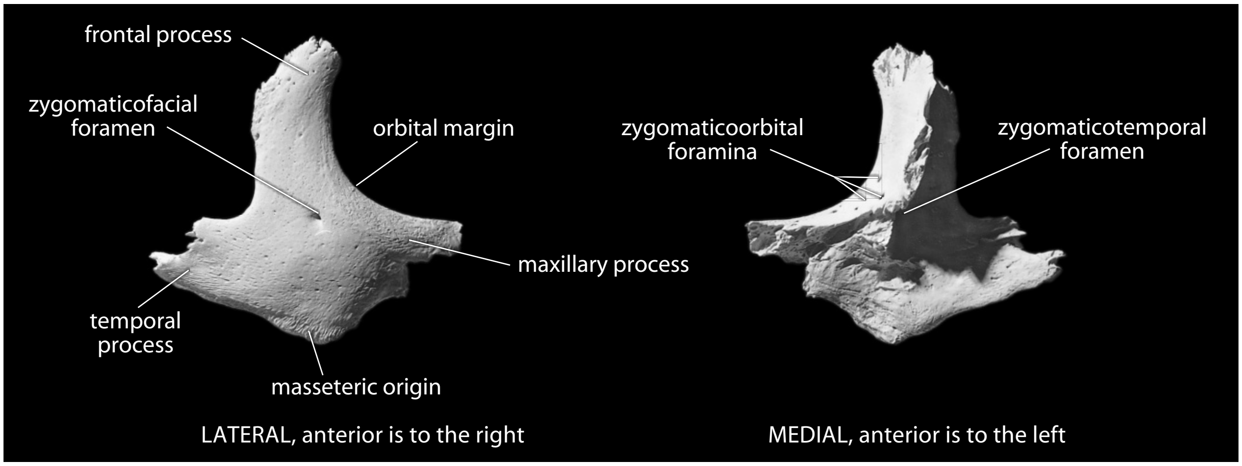


Figure 4.32 **Right zygomatic.** Superior is up. Natural size.

a. The **frontal process** rises vertically and separates the orbit from the temporal fossa.
b. The **temporal process** extends posteriorly, joining the zygomatic process of the temporal bone to form the zygomatic arch.
c. The **maxillary process** extends toward the midline, forming the inferolateral orbital margin.
d. The **zygomaticofacial foramen** perforates the convex lateral surface of the zygomatic. It is often multiple, allowing the passage of the *zygomaticofacial nerve* (a division of cranial nerve 5) and *vessels*.
e. The **masseteric origin**, the roughened, expanded inferior edge of the bone, extends from the zygomaticomaxillary to the temporozygomatic suture (and on to the temporal). This is the main attachment point for the *masseter muscle*, a major elevator of the mandible.
f. **Zygomaticoorbital foramina** perforate the inferolateral corner of the orbital cavity for the passage of the *zygomaticotemporal* and *zygomaticofacial nerves* (also divisions of cranial nerve 5).
g. The **zygomaticotemporal foramen** is centered in the temporal surface of the zygomatic. It transmits the *zygomaticotemporal nerve*.

4.19.2 Growth

The zygomatic bone ossifies from three centers that fuse into a single combined center during fetal development.

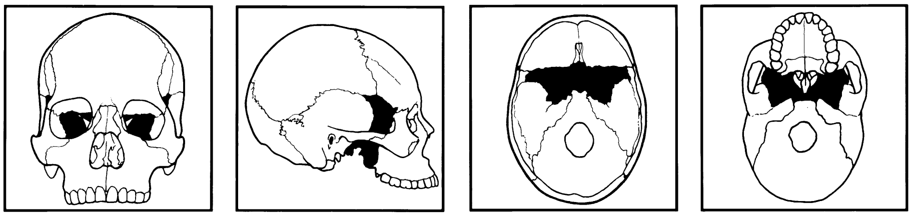
4.19.3 Possible Confusion

The three diagnostic borders of the zygomatic bone make identification easy. The most frequent confusion comes in mistaking the zygomatic process of the temporal for the zygomatic bone. None of the processes of the zygomatic bone proper are as thin or extended as the zygomatic process of the temporal.

4.19.4 Siding

To side isolated or fragmentary zygomatic bones, remember the relations of this bone to the orbit, the *masseter muscle*, and the temporal fossa.

- The masseteric attachment is inferior, and the convex surface is anterior and lateral, and is perforated by foramina.
- The orbital rim is blunter than the jugal margin posterior to it.



4.20 **Sphenoid** (Figures 4.33–4.36)

4.20.1 Anatomy

The sphenoid is the most complex bone of the cranium. Although its name means "wedgelike," its shape is far more elaborate. It is very difficult to visualize this bone when working with an articulated cranium because it has surfaces that face many directions—endocranially, inferiorly, laterally, and anteriorly. The sphenoid is situated between the bones of the cranial vault and those of the face. For this reason, and because many parts of the bone are thin, the sphenoid is virtually never found intact in broken crania. Instead, portions of it adhere to other cranial pieces.

The many articulations of the sphenoid were noted above as each of the 12 bones it touches were introduced. These are reviewed in the descriptions given here. The articulating midline bones are the vomer, ethmoid, frontal, and occipital. The sphenoid also articulates with the paired parietals, temporals, zygomatics, and palatines (and sometimes, the maxillae) lateral to the midline. Examination of the sphenoid is simplified by dealing with four basic parts of the bone, the body, greater and lesser wings, and the pterygoid plates. For an overall perspective, view the sphenoid from behind, visualizing it as a flying animal with a central body, two pairs of wings, and dangling talons (the pterygoid plates).

a. The **body** is the only part of the sphenoid that lies on and immediately adjacent to the midline. This is the most substantial part of the bone. Its anterior surface forms the posterosuperior wall of the nasal cavity and articulates with the cribriform and perpendicular plates of the ethmoid. Posteriorly, the body articulates with the occipital across the spheno-occipital synchondrosis (basilar suture); anteroinferiorly it articulates with the vomer.
b. **Optic canals** are seen to either side of the body. They pass anteroinferior to the lesser wings, just medial and superior to the superior orbital fissure. The *optic nerve* (cranial nerve 2) and *ophthalmic artery* pass through these canals on their way to the eyeballs.
c. The **sella turcica** ("Turkish saddle") is a saddle-shaped depression on the endocranial surface of the sphenoid. It is located endocranially, posterior and inferior to the optic canals, atop the body of the sphenoid, decorated by the four clinoid processes.
d. The **hypophyseal** (**pituitary**) **fossa** is the deepest depression of the sella. It holds the *pituitary gland*, the manufacturer of growth hormones.
e. The **dorsum sellae** is the square plate of bone that forms the posterior boundary of the sella turcica.
f. The **posterior clinoid processes** are the two highly variable tubercles located at the superolateral corners of the dorsum sellae.
g. The **clivus** is the slight endocranial hollow that slopes posteriorly from the dorsum sellae toward the basilar suture.
h. The **sphenoidal sinuses** are large, paired hollows within the body of the sphenoid.
i. The **sphenoidal rostrum** is a midline bony projection on the anteroinferior surface of the body of the sphenoid. It fits into the fissure between the alae of the vomer.

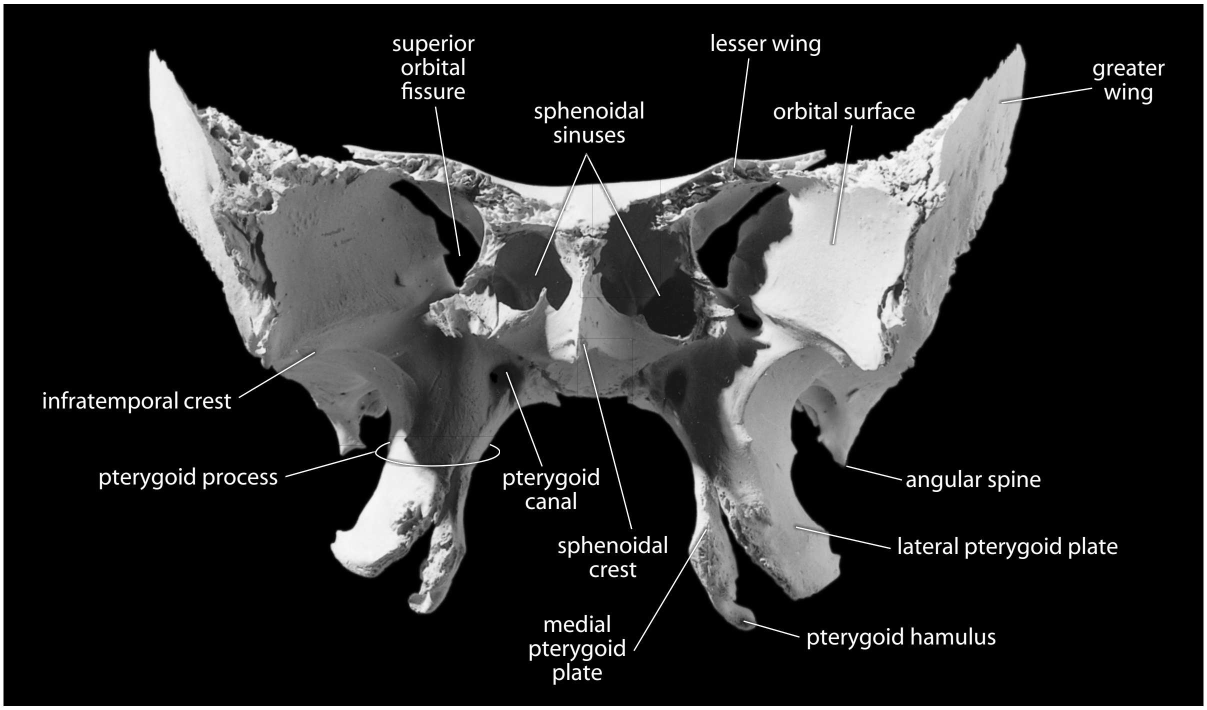


Figure 4.33 **Sphenoid, anterior.** Superior is up. Natural size.

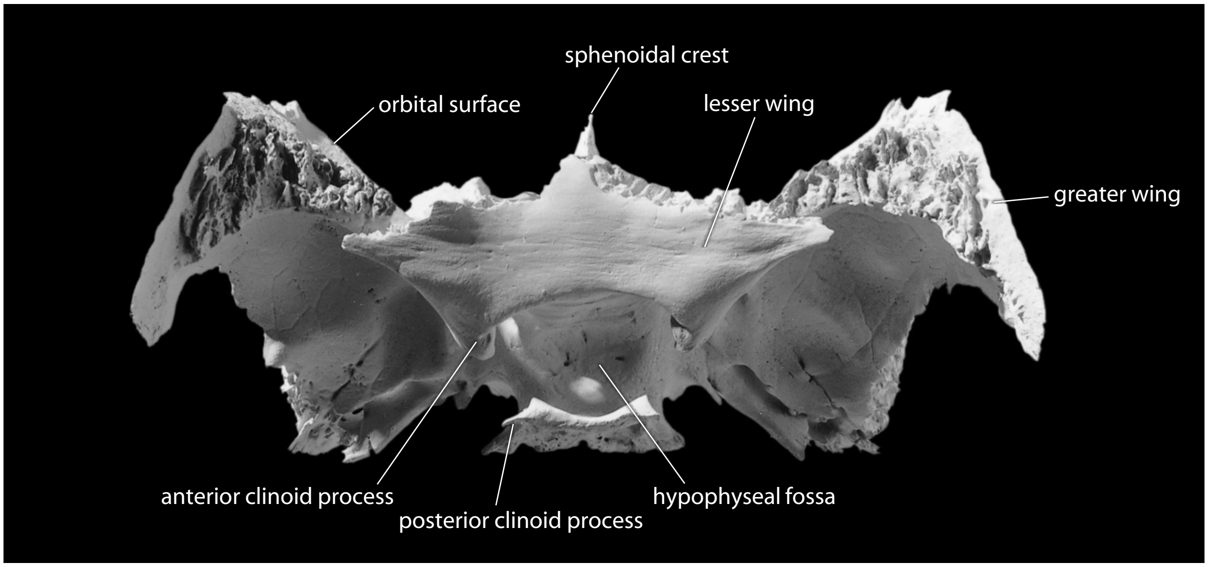


Figure 4.34 **Sphenoid, superior (endocranial).** Anterior is up. Natural size.

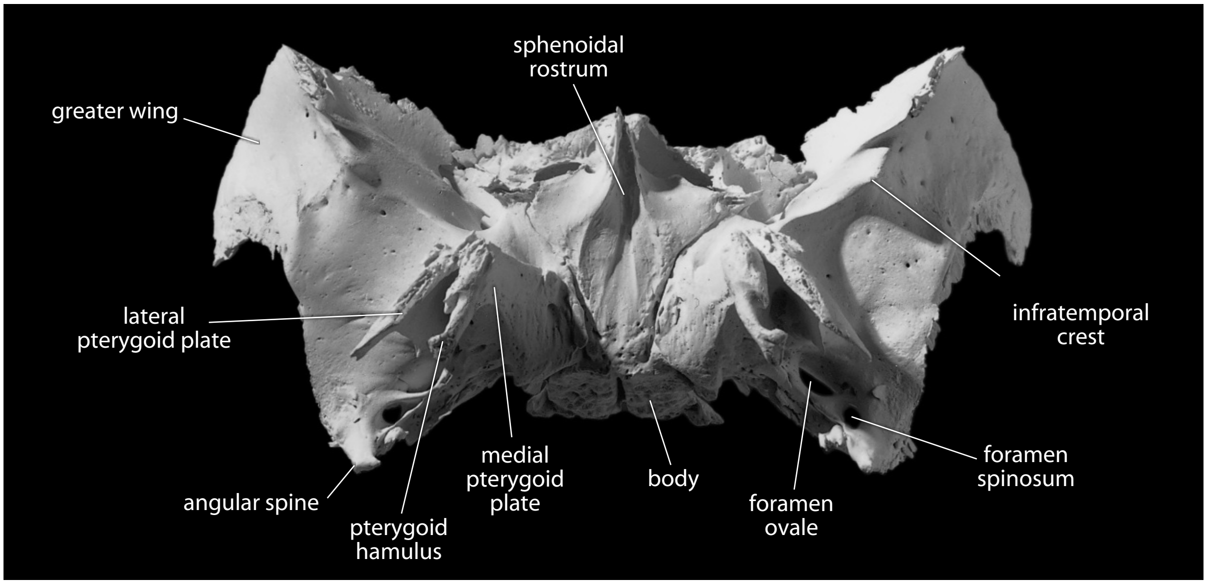


Figure 4.35 **Sphenoid, inferior.** Anterior is up. Natural size.

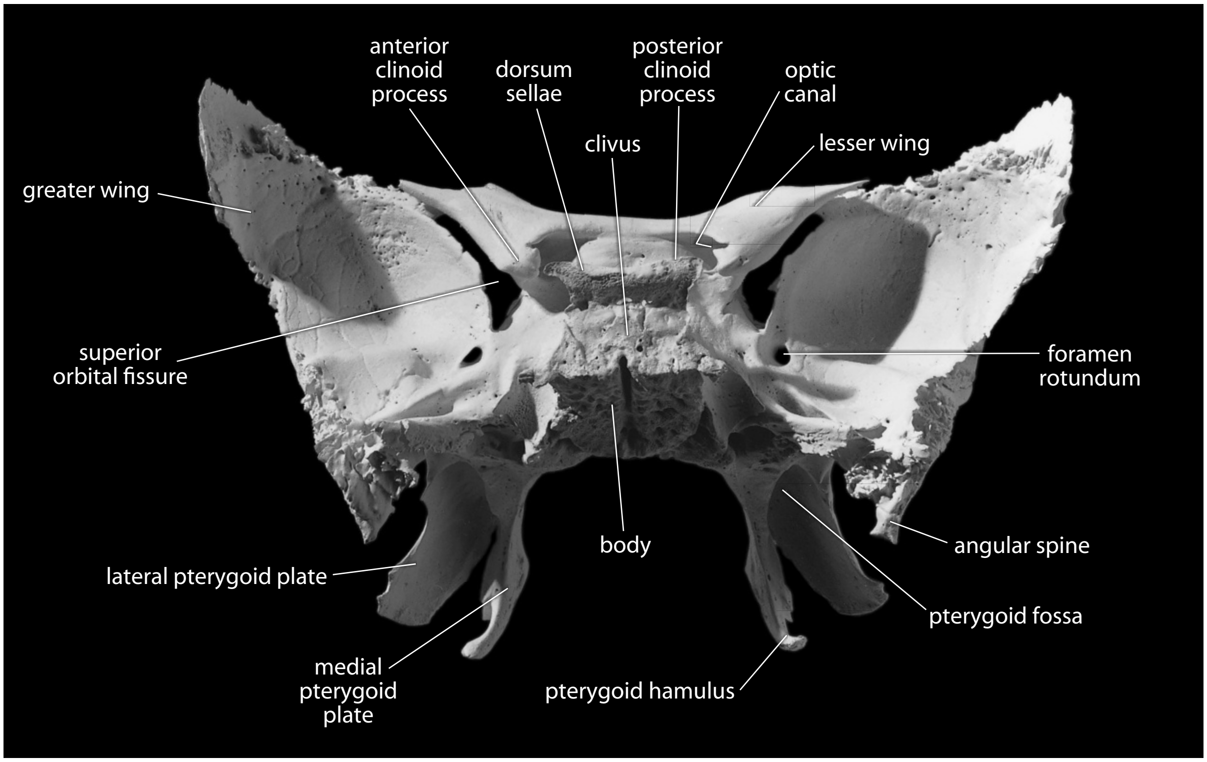


Figure 4.36 **Sphenoid, posterior.** Superior is up. Natural size.

j. The **sphenoidal crest** is continuous with the rostrum, extending superiorly from it on the anterior surface of the body of the sphenoid. This midline sphenoidal crest articulates with the perpendicular plate of the ethmoid and forms part of the septum of the nose.

k. The **greater wings** of the sphenoid (right and left) are attached to the body. They are the segments that extend the farthest laterally from the body, forming most of the middle cranial fossae endocranially and much of the temporal fossae ectocranially. The greater wings articulate with the temporals, parietals, frontal, zygomatics, and maxillae.

l. The **superior orbital fissures** are the open spaces (gaps) between the inferior surfaces of the lesser wings and the anterior surfaces of the greater wings. The fissures are visible at the back of the orbits in an anterior view of the cranium. The superior orbital fissure and three foramina identified later are best seen on the endocranial surface of the sphenoid. These openings are arranged in the form of an arc that sweeps posterolaterally from the midline in the area where the greater wing and body merge. The arc is sometimes called the "crescent of foramina."

m. The **foramen rotundum** is situated in the most anterior and medial part of the middle cranial fossae at the junction of the greater wings and the body. These foramina transmit the *maxillary nerves* (another division of cranial nerve 5) that run just inferior to the superior orbital fissures.

n. The **foramen ovale** is located posterior to the foramen rotundum on each side, approximately in line with the dorsum sellae in endocranial view. These foramina transmit the *mandibular nerves* and *accessory meningeal arteries*.

o. The **foramen spinosum** is located on each greater wing just posterolateral to the foramen ovale. The foramina spinosa are set in the posteroinferior spines of the sphenoid, very close to the temporal bones. They transmit the *middle meningeal vessels* and branches from the *mandibular nerves*.

p. The **infratemporal crests** mark the ectocranial surfaces of the greater wings. They form the base of the temporal fossae at about the level of the zygomatic arches.

q. The **orbital surfaces** of the greater wings of the sphenoid, which form the lateral wall of each orbit, are very smooth and flat in comparison to the endocranial surfaces.

r. The **lesser wings**, which are much smaller than the greater, are thin, wing-shaped posterior projections of the endocranial surface. These partially floor the right and left frontal lobes of the brain. They arise from the superior surface of the body and articulate with the horizontal orbital plates of the frontal.

s. The **anterior clinoid processes** are the posteriormost projections of the lesser wings. These give attachment to the *tentorium cerebelli*, a segment of *dura mater* that separates the cerebellum from the occipital part of the *cerebral hemispheres* of the brain.

t. The **angular spine** (or **sphenoid spine**) is the inferiormost projection of the greater wing, located posterior to foramina spinosum and ovale. It serves as an attachment point for the *pterygospinous ligament*.

u. The **pterygoid processes** of the sphenoid are visible only from below or to the side of the cranium. The pterygoid processes are each divided into two thin plates.

v. The **lateral pterygoid plate** (or **lamina**) is a thin vertical plate of bone seen in lateral view of the cranium.

w. The **medial pterygoid plate** (or **lamina**) is a thin vertical plate of bone that roughly parallels the lateral plate in orientation but is set closer to the midline. Each pair of pterygoid plates articulates anteriorly with the palatines. These four thin projections provide attachment for the *medial pterygoideus muscles*, mandibular elevators.

x. **Pterygoid fossae** are rough-floored hollows between the medial and lateral pterygoid plates.

y. The **pterygoid hamulus** is the hook-like process forming the posterolateral, basal corner of each medial pterygoid plate.

z. **Pterygoid canals** perforate the bone above the pterygoid plates and run along the base of these plates.

4.20.2 Growth

The sphenoid is mostly formed in cartilage; only the pterygoid plates form dermally. Growth is complex, with a number of centers of ossification involved, but this bone is recognizable by the time of birth.

4.20.3 Possible Confusion

Because it has so many parts, broken fragments of sphenoid are often difficult to identify. Only an intensive study of the various anatomical parts introduced above will allow confident identification of isolated fragments. Fortunately, fragments of sphenoid are usually attached to other cranial bones, and identification is aided by this fact. The parts most often found isolated are the greater wings and the body.

The nature of the suture between the temporal, parietal, and sphenoid helps in the identification and siding of sphenoid fragments. The sphenoid overlaps the parietal superiorly and underlaps the temporal posteriorly. It abuts the temporal in basicranial aspect.

4.20.4 Siding

- For pterygoid plates, the pterygoid fossa faces posteriorly, and the plates have nonarticular, sharp posterior and inferior edges.
- For the greater wing, the smooth, flat orbital surfaces face anteriorly, and the concave temporal surfaces face laterally.
- The endocranial surface is posterosuperior, and its base is marked by the foramina rotunda, ovale, and spinosa. The latter foramen is at the spine of the greater wing, the most posterolateral extent of the wing, often on the sphenosquamous suture.
- For a fragmentary lesser wing, the free, nonarticular end is posterior, the wing tips face laterally, and parts of the frontal often adhere anteriorly. The anterior clinoid process points posteriorly.

4.21 Mandible (Figures 4.37–4.39)

4.21.1 Anatomy

The mandible, or lower jaw, articulates through its condyles (via an articular disk) with the temporal bones at the temporomandibular joint. The primary function of this bone is in **mastication** (chewing). The mandible holds the lower teeth and provides insertion surfaces for the muscles of mastication. These two functions are performed by the two basic parts of the mandible: the body (corpus) and the ascending ramus.

a. The **body** (or **corpus**, or **horizontal ramus**) is the thick, bony part of the mandible that anchors the teeth. With its implanted teeth, the corpus of the mandible is very hard, dense, and resistant to destruction. For this reason, mandibular corpora outlast other body parts in bone assemblages that have been ravaged by carnivores or subjected to physical degradation.

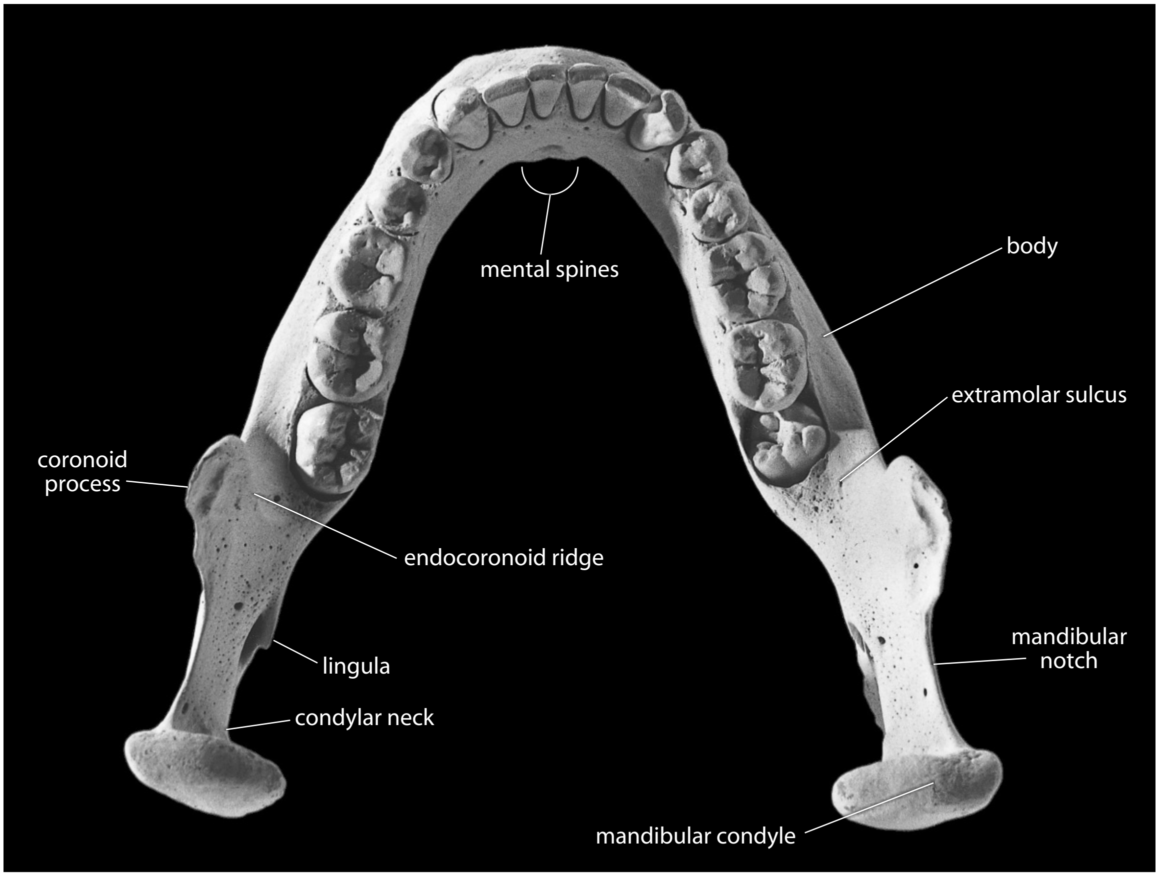


Figure 4.37 **Mandible, superior.** Natural size.

b. The **alveolar portion** of the corpus contains the **alveoli** for the tooth roots, except where these have been resorbed following the loss of teeth.

c. The **mental foramen** is the large, sometimes multiple foramen located on the lateral corpus surface, near mid-corpus, below the premolar region. This foramen transmits the *mental vessels* and *nerve* (another division of cranial nerve 5).

d. The **oblique line** is a weak eminence that passes from the root of the ramus to the area at the rear of the mental foramen.

e. The **extramolar sulcus** is the gutter between the root of the anterior edge of the ramus and the lateral alveolar margin of the last molar. This area gives rise to the *buccinator muscle*, the muscle of the cheek.

f. The **mylohyoid line** obliquely crosses the medial surface of the corpus, beginning near the alveolar margin at the last molar position and diminishing as it runs anteroinferiorly. It marks an attachment site for the *mylohyoid muscle*, a muscle that forms the muscular floor of the oral cavity and acts to elevate the *tongue* and hyoid bone.

g. The **submandibular fossa** is the hollow beneath the alveolar portion that runs along the medial corpus, inferior to the mylohyoid line. In life, the *submandibular gland*, one of the salivary glands, rests in this fossa.

h. The **sublingual fossa** is the hollowing beneath the alveolar region, superior to the my-

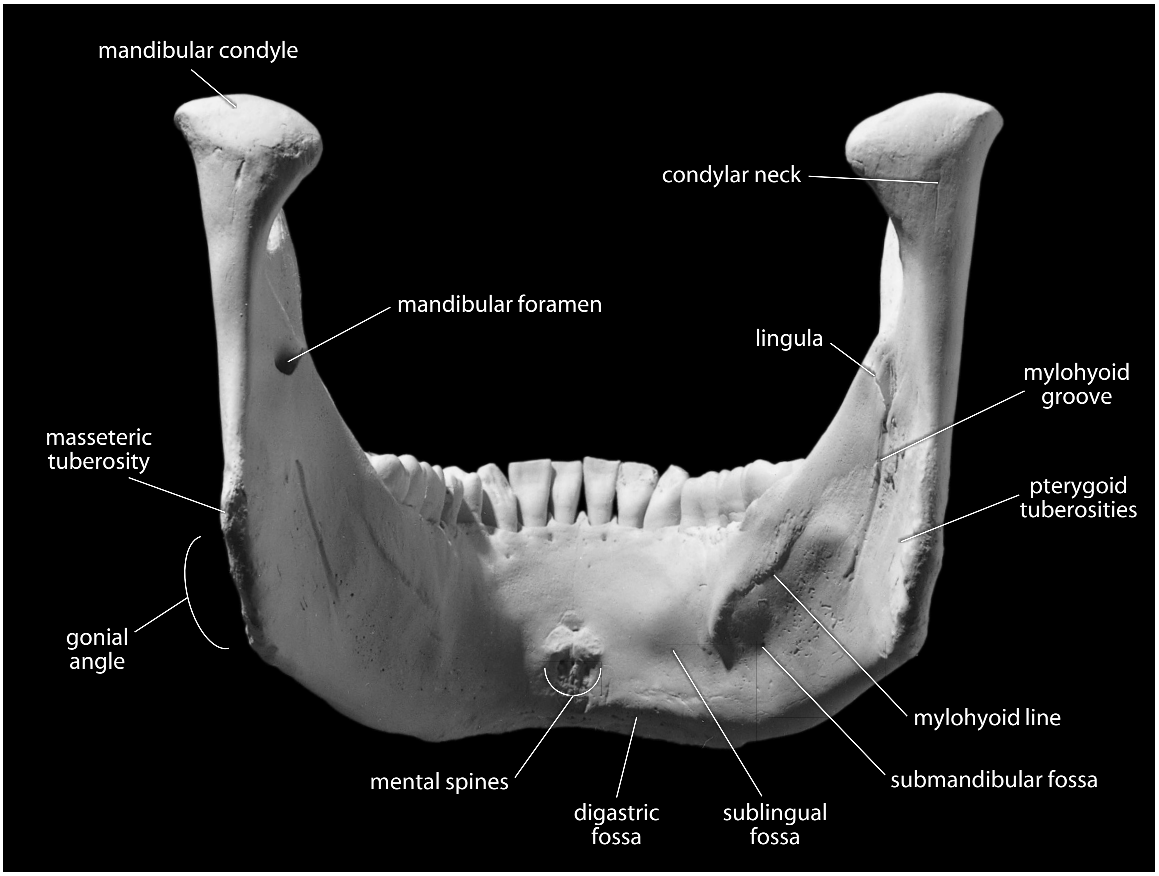


Figure 4.38 **Mandible, posterior.** Natural size.

lohyoid line in the premolar region. The *sublingual gland*, another salivary gland, rests in this fossa.

i. A **mandibular torus** is the variably developed thickening of the alveolar margin just lingual to the cheek teeth. This feature takes on a billowed appearance in its most extreme manifestations but is often imperceptible.

j. The **mandibular symphysis** technically refers only to the midline surfaces of unfused right and left mandibular halves in individuals less than 1 year of age. It is often used as a more general term referring to the anterior region of the mandible between the canines.

k. The **mental spines** lie near the inferior margin of the inner (posterior) surface of the anterior corpus. They are variable in prominence and anchor the *genioglossus* and *geniohyoid muscles*, muscles of the tongue.

l. The **digastric fossae** are the pair of roughened depressions on the posteroinferior aspect of the corpus adjacent to the midline. They face posteroinferiorly and are attachment sites for the *digastric muscles*, depressors of the mandible.

m. The **mental protuberance** (or **eminence**) is the triangular eminence, or bony chin, at the base of the corpus in the anterior symphyseal region. It is separated from the alveolar margins of the incisors by a pronounced incurvation or "mental sulcus" (or the "labiomental sulcus" if flesh is still attached to the depression) in modern humans.

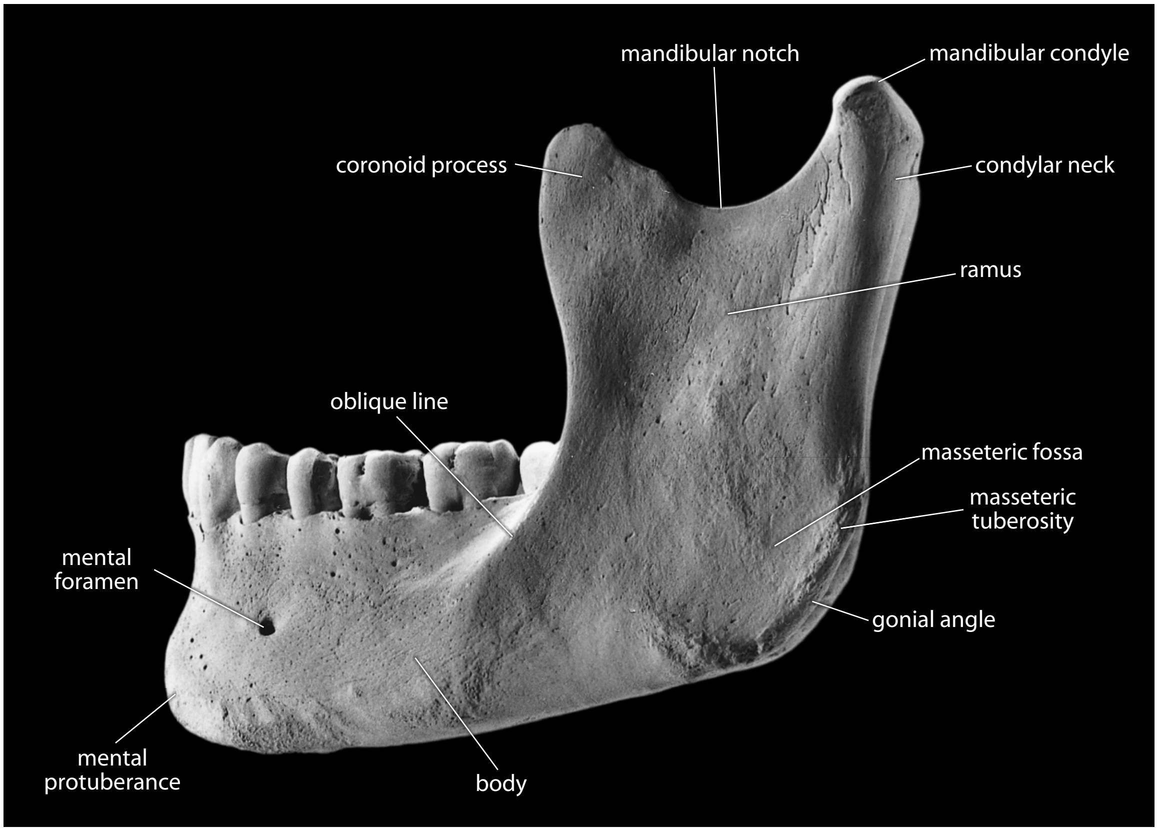


Figure 4.39 **Mandible, lateral.** Natural size.

n. The **ramus** (or **ascending ramus**) is considerably thinner than the corpus. This vertical part of the mandible rises above the level of the teeth and articulates with the cranial base.

o. The **mandibular condyle** is the large, rounded, articular prominence on the posterosuperior corner of the ramus. It articulates at the temporomandibular joint.

p. The **condylar neck** is the area just anteroinferior to the condyle. A head of the *lateral pterygoideus muscle* attaches to the anteromedial surface of the neck just below the articular surface of the condyle, in the **pterygoid fovea**. This muscle acts to depress and stabilize the mandibular condyle during chewing.

q. The **coronoid process** of the ramus is thin and triangular, varying widely in shape and robusticity. Its anterior border is thickened and convex, and its posterior edge is concave and thinner. Both medial and lateral surfaces of this process receive the insertion of the *temporalis muscle*.

r. The **mandibular notch** (or **incisura**) is the notch between the condyle and the coronoid process.

s. The **gonial angle** is the rounded posteroinferior corner of the mandible. The *masseter muscle* attachment is centered on the lateral surface of the ramus, all along the angle.

t. The **masseteric tuberosity** is the raised, roughened area at the lateral edge of the gonial angle at which the *masseter muscle* attaches. This area is often joined by oblique ridges

raised by *masseter* attachment. When the edge of the gonial angle projects far laterally from the rest of the ramus, the gonial area is said to be strongly **everted**.

u. The **masseteric fossa** is a variably expressed hollowing on the lateral surface of the gonial angle.

v. The **endocoronoid ridge** (or **buttress**) is the vertical ridge extending inferiorly from the coronoid tip on the inner (medial) aspect of the ramus.

w. The **mandibular foramen** enters the bone obliquely, centered in the medial surface of the ramus. The *alveolar vessels* and *inferior alveolar nerve* (a division of cranial nerve 5) enter the bone through this opening, running through the mandible via the **mandibular canal**.

x. The **lingula** is a sharp, variably shaped projection at the edge of the mandibular foramen. It is the attachment point for the *sphenomandibular ligament*.

y. The **mylohyoid groove** (or **sulcus**) crosses the medial surface of the ramus, running anteroinferiorly from the edge of the mandibular foramen. It lodges the *mylohyoid vessels* and *nerve*.

z. **Pterygoid tuberosities** interrupt the medial surface of the gonial angle posteroinferior to the mylohyoid groove. They mark the insertion of the *medial pterygoideus muscle*, an elevator of the mandible.

4.21.2 Growth

The mandibular halves are separate at birth; they join during the first year at the symphysis. At birth the mandible holds unerupted deciduous teeth in crypts below the surface. The eruption of these teeth and their permanent counterparts effects dramatic changes on the mandible during ontogeny. Loss of permanent teeth results in resorption of the alveolar portion of the mandible.

4.21.3 Possible Confusion

Only small fragments of mandible can be confused with other bones. Where tooth sockets are present, the bone must be the maxilla or mandible. The former has a sinus above the molar roots.

- The mandibular corpus has a much thicker cortex than the maxilla, as well as a basal contour.
- The coronoid process might be mistaken for thin cranial bones, such as the sphenoid or zygomatic. Note, however, that the coronoid does not articulate and its edges are therefore nonsutural.

4.21.4 Siding

To side fragments of the mandible, remember that the incisors are anterior and closer to the midline than the molars, and that the ramus is posterior, with greater relief on its medial surface.

- For isolated condyles, the border of the mandibular notch is continuous with the lateral side of the condyle (most of the condyle itself lies medial to the plane of the ramus).
- For isolated coronoids, the notch is posterior, the tip superior, and the endocoronoid ridge is medial.
- For isolated gonial angles, the tuberosities for the *medial pterygoideus* are medial and are anterosuperiorly directed.

4.22 Measurements of the Skull: Craniometrics

Measurements of the skull are used for sex determination, age estimation, racial affinity, biomechanical load calculations, analyses of encephalization, and others. A huge number of potential chords, arcs, volumes, and indices can be defined, measured, and calculated on any human skull, according to the particular research or documentary goals of the metrician. A basic set of commonly used measurements taken on intact skulls was defined by Buikstra and Ubelaker (1994), and serves as a baseline and introduction to this topic. They recommend that 34 standard cranial measurements be taken on intact skulls. The "Standards" metrics of Buikstra and Ubelaker (1994) are presented below, along with adjusted descriptive terms and additional useful metrics and indices (see Section 4.5 for osteometric point abbreviations and definitions).

4.22.1 Cranial Measurements

1. **Maximum cranial length: (g–op)**
2. **Maximum cranial breadth: (eu–eu)**
3. **Bizygomatic breadth (or diameter): (zy–zy)**
4. **Biauricular breadth: (au–au)**
5. **Maximum cranial height (or basion–bregma height): (ba–b)**
6. **Cranial base length: (ba–n)**
7. **Basion–prosthion length: (ba–pr)**
8. **Frontal chord: (n–b)**
9. **Parietal chord: (b–l)**
10. **Occipital chord: (l–o)**
11. **Total facial height: (gn–n)**
12. **Upper facial height: (pr–n)**
13. **Upper facial breadth: (fmt–fmt)**
14. **Minimum frontal breadth: (ft–ft)**
15. **Nasal aperture height (or nasal height): (ns–n)**
16. **Nasal aperture breadth (or nasal breadth): (al–al)**
17. **Orbital height: (greatest, perpendicular to breadth)**
18. **Orbital breadth: (d–ec)**
19. **Biorbital breadth: (ec–ec)**
20. **Interorbital breadth: (d–d)**
21. **Palate length: (ol–sta)**
22. **Palate breadth: (enm–enm)**
23. **Maxillo-alveolar breadth: (ekm–ekm)**
24. **Maxillo-alveolar length: (pr–ids)**
25. **Foramen magnum length: (ba–o)**
26. **Foramen magnum breadth: (greatest, perpendicular to length)**
27. **Mastoid length: (vertical component of au–ms)**
28. **Bicondylar breadth: (cdl–cdl)**
29. **Bigonial breadth: (go–go)**
30. **Mandibular length: (horizontal component of pg–go)**

31. **Mandibular angle: (angle between inferiormost two points of corpus and the posteriormost two points of ramus + condyle)**
32. **Maximum ramal breadth: (anteriormost of ramus – line connecting the posteriormost two points of ramus + condyle)**
33. **Minimum ramal breadth: (smallest, perpendicular to height)**
34. **Maximum ramal height: (cs–go)**
35. **Mandibular body height: (base–alveolar margin, at mental foramen)**
36. **Mandibular body breadth: (maximum breadth at mental foramen)**
37. **Symphyseal height (or chin height): (gn–id)**

4.22.2 Cranial Indices

1. **Cranial index: (cranial breadth ÷ cranial length) × 100**
2. **Cranial module: (cranial length + cranial breadth + cranial height) ÷ 3**
3. **Cranial length-height index: (cranial height ÷ cranial length) × 100**
4. **Cranial breadth-height index: (cranial height ÷ cranial breadth) × 100**
5. **Total facial index: (total facial height ÷ bizygomatic breadth) × 100**
6. **Upper facial index: (upper facial height ÷ bizygomatic breadth) × 100**
7. **Nasal aperture index: (nasal aperture breadth ÷ nasal aperture height) × 100**
8. **Orbital index: (orbital height ÷ orbital width) × 100**
9. **Palatal index: (palate breadth ÷ palate length) × 100**

4.23 Cranial Nonmetric Traits

Whereas there are dozens of cranial nonmetric traits, Buikstra and Ubelaker (1994) consider 21 of them to be of particular importance. The 21 traits from Buikstra and Ubelaker (1994) are listed below. Note that when a trait cannot be evaluated because the anatomy is not preserved, the trait is scored as "unobservable."

- **Persistent metopic suture**: The metopic suture will often remain patent (unfused) beyond childhood. This trait is usually scored as complete (*i.e.,* unfused), absent (fused), or partial.
- **Supraorbital notch or foramen**: The presence, number, and occlusion of supraorbital structures should be documented. For each orbit, note whether supraorbital foramina are absent, present, or multiple. Incompletely closed foramina are called notches. Note whether notches are absent, present, or multiple, and estimate whether the notch is more or less than 50% occluded with spicules.
- **Persistent infraorbital suture**: Usually scored as absent, partial, or complete.
- **Multiple infraorbital foramina**: Note whether absent (*i.e.,* has only a single foramen), internally subdivided, two distinct foramina, or more than two distinct foramina.
- **Size and number of zygomaticofacial foramina**: The standard choices for this trait are: absent, a single large foramen, one large and any number of smaller foramina, two large foramina, two large foramina and any number of smaller foramina, a single small foramen, or multiple small foramina.

- **Presence of a parietal** (or **obelionic**) **foramen**: For each side, determine whether a parietal foramen (near obelion) is present or absent on the outer table of the parietal. If present, is it located on the parietal proper, or within the sagittal suture?
- **Presence of sutural bones**: Note the presence or absence of each of these named ossicles: epipteric bone, coronal ossicle, bregmatic bone, sagittal ossicle, apical bone, lambdoid ossicle, asterionic bone, occipitomastoid ossicle, and parietal notch bone.
- **Presence of an inca bone**: Note whether an inca bone is absent, partial, or complete, as well as whether it's single, bipartite, or tripartite.
- **Patent condylar canal**: Record whether the canal is patent (open) or nonpatent.
- **Divided hypoglossal canal**: Bony extensions will sometimes completely or partially divide the hypoglossal canal. For each side, determine whether such a division exists, whether it is complete or partial, and whether the division is inside the canal or on its medial/endocranial surface.
- **Flexure of superior sagittal sulcus**: Note whether the superior sagittal sulcus turns right, turns left, or bifurcates at the internal occipital protuberance.
- **Incomplete foramen ovale**: Is the foramen ovale distinct from foramen lacerum, or do the margins of both combine into a single, irregular opening?
- **Incomplete foramen spinosum**: Is the foramen spinosum distinct from foramen lacerum, or do the margins of both combine into a single, irregular opening?
- **Pterygospinous bridge or spur**: The pterygospinous ligament (extending from the angular spine to the lateral pterygoid plate) is sometimes ossified to a greater or lesser extent. If the ossification completely bridges the gap, it is called a bridge; otherwise, it is called a spur. An example of a pterygospinous spur can be seen on the left side of the individual in Figure 4.5.
- **Pterygo-alar bridge** (or **bar**): The pterygo-alar ligament (extending from the lateral pterygoid plate to just medial of foramen ovale) typically ossifies into a 'bar' in lemurs and monkeys, but is only rarely so in apes and humans. If the ossification bridges the gap, it is called a bridge (or bar); otherwise, it is a spur.
- **Tympanic dehiscence**: During the first years of life, the tympanic portion of the temporal ossifies, except for a opening called the **Foramen of Huschke**, which is itself usually ossified by the age of 5. When this foramen remains patent into adulthood, it is referred to as tympanic dehiscence.
- **Auditory exostosis (or torus)**: Is the external acoustic meatus occluded to any degree by a bony nodule? If so, is it <⅓ occluded, ⅓ – ⅔ occluded, or >⅔ occluded?
- **Mastoid foramen**: For each side, is a mastoid foramen present or absent? If present, is there one, two, or more than two foramina? Note whether the foramina are located on the occipital bone, the temporal bone, and/or within the occipitomastoid suture.
- **Multiple mental foramina**: For each side, is a mental foramen present or absent? If present, is there one, two, or more than two foramina?
- **Mandibular torus**: For each side, is a distinct mandibular torus present or absent? If present, is it barely perceptible, moderate (2–5 mm projection) or marked (>5 mm projection)?
- **Mylohyoid bridge**: There may be a partial or complete bony bridge over the mylohyoid groove. If so, is it near the mandibular foramen, near the center of the groove, or both? If both, is there a gap between the two parts of the bridge, or is it continuous?

4.24 Mastication

Rather than studying bones as inert objects with strange names and processes, they are best appreciated as the living foundations of the organism. Our introduction to the skull revealed bony structures that house a variety of organs such as the brain and the eyes. Much of the anatomy of the skull is devoted to its function in chewing. Study of the masticatory system has given physical anthropologists insight into the diet of extant and extinct primates, including human ancestors. It is useful to conclude our examination of the skull with an analysis of the musculoskeletal system behind human mastication. This analysis provides an excellent reminder that the external and internal architecture of bones is strongly related to function.

Chewing takes place through the coordinated action of the musculoskeletal system of the head. Abundant evidence of the soft-tissue components of this system has been noted in the form of muscular and ligamentous attachments. Foramina and grooves for blood vessels and nerves on the mandible, zygomatics, frontal, parietals, temporals, and other bones are more evidence of soft tissues.

The masticatory system is devoted to generating forces across the opposing mandibular and maxillary teeth. There are elevators of the mandible (muscles that pull the lower jaw and its teeth up and against the maxillary teeth) and depressors of the mandible. The primary muscles that elevate the mandible during chewing (and their major attachments) are as follows: The ***temporalis muscle*** originates on the side of the cranial vault inferior to the superior temporal line and inserts on the sides, apex, and anterior surface of the coronoid process of the mandible. The ***masseter muscle*** originates on the inferior surface of the zygomatic arch and inserts on the lateral surface of the mandibular ramus and the gonial angle of the mandible. The ***medial pterygoideus muscle*** originates on the medial surface of the lateral pterygoid plate of the sphenoid and inserts on the medial surface of the mandibular gonial angle.

When the teeth are forcefully clenched, it is easy to palpate the active *masseter* and *temporalis muscles* on either side of the jaw and temple. The act of clenching involves stimulation of fibers in each of these muscles. This stimulation comes from nerves which can be traced back to the brain. The muscle fibers contract, and this contraction brings the bony attachment points of the muscles closer together, forcefully elevating the mandibular teeth against their maxillary counterparts. Any food between the teeth is reduced by this activity to a smaller size and then passed farther down into the digestive system. All of this coordinated, complex working of the masticatory system takes place thousands of times each day without our paying much attention to it.

Suggested Further Readings

The descriptions of cranial anatomy in this chapter, and the descriptions of postcranial anatomy in Chapters 6–13, may be supplemented by any of several osteology and anatomy texts.

Abrahams, P. H., Boon, J. M., Spratt, J. D., Hutchings, R. T., and McMinn, R. M. H. (2007) *McMinn's clinical atlas of human anatomy* (6th ed.). St. Louis, MO: Mosby/Elsevier. 386 pp. + DVD.

Excellent photographic illustrations in a large, well-organized format.

Agur, A. M. R., and Dalley, A. F. (2008) *Grant's atlas of anatomy* (12th ed.). Philadelphia, PA: Lippincott Williams & Wilkins. 834 pp.

A large-format, soft-bound atlas, excellent as a quick laboratory reference for examining the relationships between bones and soft tissues.

Bass, W. M. (2005) *Human osteology: A laboratory and field manual* (5th ed.). Columbia, MO: Missouri Archaeological Society. 365 pp.

An introductory manual emphasizing identification.

Buikstra, J. E., and Ubelaker, D. H. (Eds.) (1994) *Standards for data collection from human skeletal remains.* Fayetteville, AR: Arkansas Archaeological Survey. 206 pp.

The standard work to consult when documenting human remains.

Cartmill, M., Hylander, W., and Shafland, J. (1987) *Human structure.* Cambridge, MA: Harvard University Press. 448 pp.

A functionally and evolutionarily oriented introductory anatomy textbook.

Krogman, W. M., and İşcan, M. Y. (1986) *The human skeleton in forensic medicine* (2nd ed.). Springfield, IL: C. C. Thomas. 551 pp.

An essential source book—the descriptions and references to work on skeletal growth make good supplements to this book.

Matshes, E. W., Burbridge, B., Sher, B., Mohamed, A., and Juurlink, B. (2004) *Human osteology & skeletal radiology: An atlas and guide.* Boca Raton, FL: CRC Press. 448 pp.

An introductory text on human osteology that incorporates large numbers of plain film radiographs, CT scans, and MRI images alongside photographs of bones.

Sampson, H. W., Montgomery, J. L., and Henryson, G. L. (1991) *Atlas of the human skull.* College Station, TX: Texas A&M University Press. 200 pp.

A black-and-white photographic atlas picturing all the bones of the skull. The photographs are presented in different scales depending on the size of the bone pictured.

Schaefer, M., Black, S., and Scheuer, L. (2009) *Juvenile osteology: A laboratory and field manual.* San Diego, CA: Academic Press. 384 pp.

A handy spiral-bound guide to immature human osteology. Includes a series of forms useful for the inventory and age determination of immature remains.

Standring, S. S. (2008) *Gray's anatomy: The anatomical basis of clinical practice* (40th ed.). New York, NY: Churchill Livingstone. 1576 pp.

This continually updated classic is the most complete single reference available in the field of human anatomy.

Steele, D. G., and Bramblett, C. A. (1988) *The anatomy and biology of the human skeleton.* College Station, TX: Texas A&M University Press. 291 pp.

An atlas dedicated to the identification and biology of the human skeleton.